

State of California  
The Resources Agency  
DEPARTMENT OF WATER RESOURCES  
Northern District

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**COLUSA BASIN DRAIN  
WATER QUALITY  
LITERATURE REVIEW**

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**Memorandum Report**

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## SUMMARY

This report presents a literature review of water quality in the Colusa Basin Drain (CBD), identifies potential impacts of alternatives to control flooding and drainage in the CBD, and recommends further study needs with respect to water quality in the CBD.

The Colusa Basin is primarily an agricultural area having poor quality soils with respect to texture and alkalinity. The fine textured, low permeability soils on the valley floor support primarily rice and pasture. The basin has valuable wildlife habitat for waterfowl and pheasants, including three National Wildlife Refuges, many private gun clubs, and other wetland areas. The drainage canals in the area support a good warm-water fishery.

Most of the water supply comes from the Sacramento River via the Tehama-Colusa Canal and the Glenn-Colusa Canal. In addition, diversions from westside streams and ground water supplement the basin's water supply. Irrigated agriculture, wildlife refuges, and private gun clubs are the primary water users. Nearly 75 percent of the water used for irrigation in the basin is consumed through evapotranspiration.

The CBD conveys runoff and agricultural return flows from about 1 million acres of watershed and discharges to the Sacramento River at Knights Landing. During high flows, the CBD is often diverted through the Knights Landing Ridge Cut to the Yolo Bypass. The CBD is the single largest source of agricultural return flows to the Sacramento River.

Temperatures in the CBD are usually higher than the Sacramento River, and the river increases in temperature below the Knights Landing outfall. The increased temperature below the outfall may be due to thermal loading from the CBD or due to atmospheric warming of the river as it flows between stations above and below the outfall.

The CBD is more alkaline than the river and may increase the pH of the river at times.

Dissolved oxygen (DO) levels are lower and fluctuate more in the CBD than the river. The river is nearly always near saturation, while the CBD is not.

The CBD water is sodium-magnesium bicarbonate in nature, while the river is calcium-magnesium bicarbonate in type. The drain water is moderately hard. Electrical conductivity (EC) and total dissolved solids (TDS) are substantially higher in the CBD and raise the EC and TDS of the river measurably. Mass loading of salts from agricultural sources may have a negative impact on the delta. Salts appear to be stored in the soil-water system of the Colusa Basin during the irrigation season and are flushed from the basin during the winter. Salts during the irrigation season are concentrated two to three times as water in the CBD is used and reused. This concentration of salts is largely due to evapotranspiration.

Nutrient data is limited, particularly in the Sacramento River immediately below the CBD. Nitrogen and phosphorus concentrations are generally higher in the drain than in the river. More data are needed to determine the impact of nutrient loading on the river.

Turbidity, suspended sediments, and color are higher in the CBD than in the river and cause an increase of these parameters in the river below the outfall. A turbidity plume is usually evident in the river where the CBD discharges. Turbidity and suspended sediments are usually higher in the winter. During the irrigation season, these parameters increase by nearly three times that of the supply waters.

Trace element data are very limited and findings are inconsistent. Total copper, lead, and selenium have been found at elevated concentrations in the CBD during some years, while being below detection limits in other years. The drain may be a major contributor of copper to the river. Copper and lead have also been found in sediments and fish in the CBD. Total mercury, while not being found in the water and sediments of the CBD, has been detected at times at elevated levels in fish. Arsenic, cadmium, chromium, nickel, and zinc have all been detected at low levels in either water, sediments, or fish from the drain. Antimony and tin have been analyzed for, but not detected.

Pesticides were not studied extensively prior to the 1980s. High concentrations of DDT (dichlorodiphenyltrichloroethane) and its breakdown products were found in fish during the 1960s from the CBD. Concentrations were still being found in fish during the early 1980s and were detected in the water in 1987.

A wide variety of organic chemicals have been found in fish from the CBD, but only toxaphene and chemical group A (the combined concentrations of various organochlorine pesticides) have exceeded National Academy of Sciences (NAS) guidelines for the protection of aquatic organisms and their predators. The CBD has also been identified as a potential source of trihalomethane precursors to the Sacramento River.

The rice herbicide issue has received much study in the CBD during the 1980s. Fish kills in the CBD from 1976 to 1983 were tied to the rice herbicide molinate. In addition, taste problems in the City of Sacramento's drinking water were attributed to the rice herbicide thiobencarb during the early 1980s. Control programs and the cooperation of many private and governmental entities have resulted in the successful reduction of off-site movement of rice herbicides into the CBD and the river. The environmental problems associated with the use of these herbicides appear to be under control.

Aquatic plants in the CBD are largely limited to periphyton in the upper half meter of the water column. Algal biomass is usually lower in the drain than in the river, even though nutrient concentrations are higher in the drain. Algal growths may be limited by turbidity and herbicides in the drain.

Some agricultural return flows are actually desirable in the CBD to maintain adequate water quality and quantity to support aquatic life and riparian vegetation.

Most structural alternatives to improve drainage and decrease flooding in the Colusa Basin have the potential to increase the export of sediments from the basin by decreasing overbank deposition. Any alternative will need to address the potential downstream impacts on flooding and water quality in the Sacramento River and the delta. Structural alternatives could also impact riparian vegetation and wetlands in the basin. Through careful planning and mitigation, these impacts could be minimized.

Most nonstructural alternatives would benefit water quality by increasing the water-holding capacity of lands in the basin, thereby decreasing erosion and sediment production.

Continued reuse of waters in the basin and increased conjunctive use of lesser quality ground water could increase salt loading in the basin and increase salt concentrations in the CBD outfall to the river. More study is needed on the impacts of conjunctive use and increased reuse.



## INTRODUCTION

The purpose of this report is to review available data and literature pertaining to water quality in the CBD, to identify any further studies needed relating to water quality in the basin, and to identify potential water quality impacts of proposed engineering alternatives designed to control drainage and flooding within the basin. This work is part of the "Colusa Basin Drain Appraisal", a 4-year program being conducted by the Northern District of the Department of Water Resources (DWR). The long-range goal of this appraisal is to develop a basin plan to provide drainage and control flooding, taking into account the effects of seepage and subsidence and the need to maintain desirable water quality (DWR, September 30, 1987).

This report is divided into two major sections. The first section is a review of the literature and data as it pertains to the stated purpose of this report. The last section (Appendix A) presents an annotated bibliography of the information reviewed.

The Colusa Basin was once swamp and overflow land that flooded periodically with high seasonal flows from the Sacramento River (U. S. Bureau of Reclamation [USBR], October 1974). The basin is approximately 75 miles long, running from Orland in Glenn County through Colusa County to Knights Landing in Yolo County (Figure 1). The area encompasses about 1,560 square miles on the west side of the Sacramento River (DWR, November 1966).

The Colusa Basin is primarily an agricultural area with soils that are of poor quality. Soils of the valley floor in the basin are alkaline, fine grained, and have low permeability (DWR, 1964). Due to the quality of soils, rice and pasture are the principal crops. In addition, orchards, sugar beets, tomatoes, wheat, alfalfa, beans, corn, barley, milo, and safflower have been grown in the area (USBR, September 1973, and DWR, June 1986). The Department of Water Resources (November 1966) found there were 274,600 irrigated acres in the Colusa Basin during 1960 and predicted that 391,000 irrigated acres would occur in the basin by 1990. The Bureau of Reclamation (June 1974) stated that 730,000 acres in the basin were cultivated, while 750,000 acres were not. The Bureau values are much higher than other land use surveys have found and may have included some lands outside of the Colusa Basin. In 1983, there were more than 450,000 acres of irrigated land between Hamilton City and Knights Landing (DWR, July 1987).

In addition to agriculture, the Colusa Basin has valuable wildlife habitat (DWR, 1964; USBR, June 1974; and USBR, October 1974). Recreation in the form of waterfowl and pheasant hunting was identified as a principal resource (DWR, 1964). The Bureau of Reclamation (June 1974 and October 1974) found that there were 12,000 acres in private gun clubs, 20,470 acres in three National Wildlife Refuges (Sacramento, Colusa, and Delevan), and about 160,000 acres of land devoted to pheasant hunting. In addition to waterfowl and pheasant, California quail and mourning dove are hunted to a lesser extent in the basin. According to U. S. Fish and Wildlife (USFS) figures from 1953 through 1974, 80 percent of the 470,000 migratory waterfowl in the Sacramento Valley during September occupies wildlife refuges (USBR, October 1974). Therefore, the basin represents an important wintering ground for Pacific flyway waterfowl. Another valuable

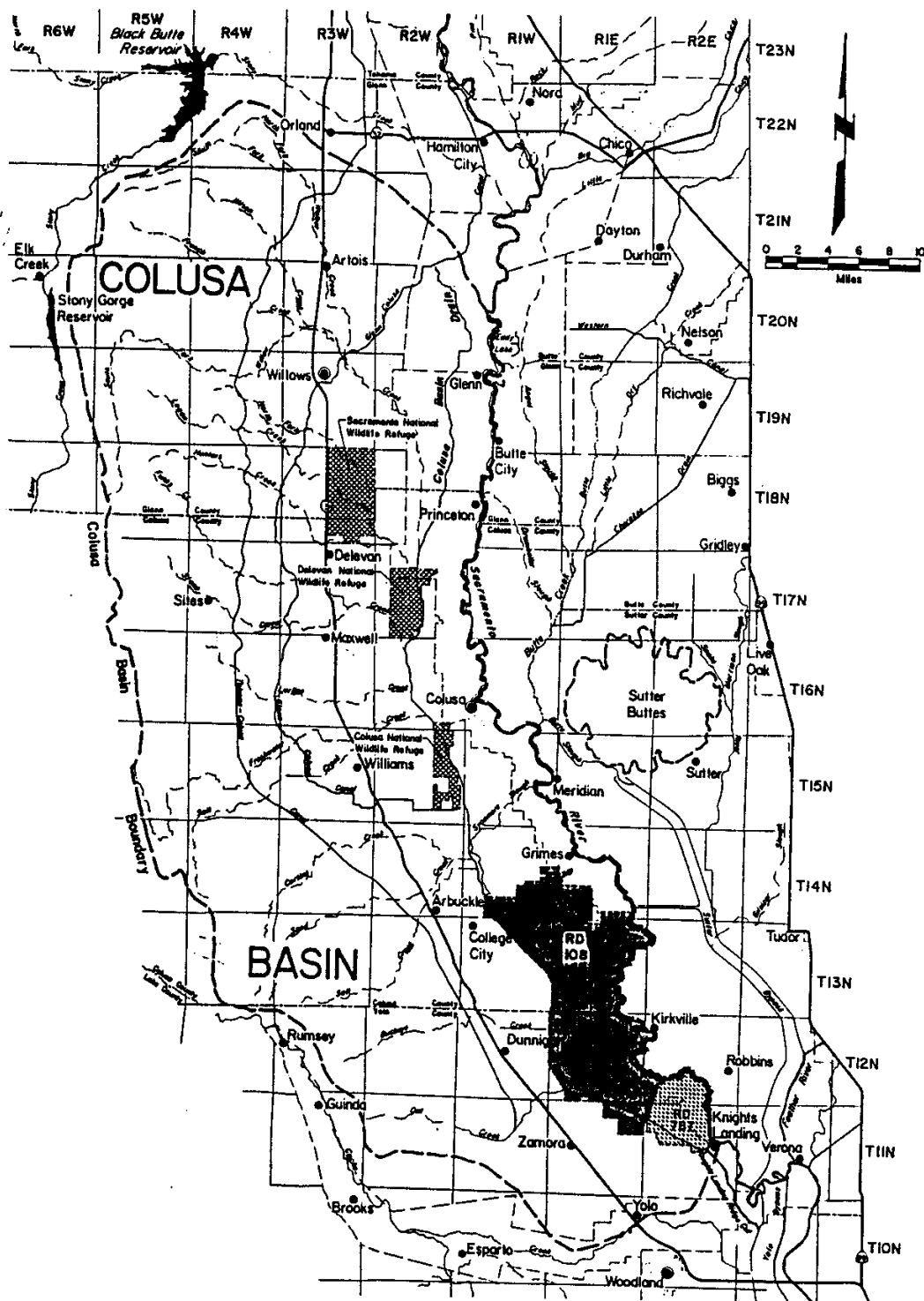


Figure 1. Location of the Colusa Basin.

resource in the Colusa Basin is the warm-water fishery. Catfish, bass, and sunfish are fished for extensively in the drains, channels, and ponds in the area.

Irrigation water is supplied to the area by way of the Glenn-Colusa Canal, Tehama-Colusa Canal, other small diversions from the Sacramento River, diversions from westside streams, and ground water (DWR, July 1987). The primary use of water in the basin is irrigated agriculture. Wildlife refuges, and private gun clubs also use water in the Colusa Basin (USBR, December 1973). Over three-quarters of the water delivered to irrigated croplands in the basin is used in rice production (University of California at Davis [UCD], 1981). The Department of Water Resources (July 1987) found that 75 percent of the water delivered for agricultural purposes was consumed through evapotranspiration. Similarly, the University of California at Davis (August 1974) found that only 27 percent of the diverted inflow made its way out of the basin during the 1973 irrigation season.

The CBD conveys flood runoff and irrigation return flows from about 1 million acres of watershed and agricultural lands in the basin (UCD, August 1974). The drain normally discharges to the Sacramento River at Knights Landing. During high river-flow periods, however, the water is diverted through the Knights Landing Ridge Cut to the Yolo Bypass (DWR, November 1966) (Figure 2). High-flow periods normally occur during winter storm events, but unusually high Sacramento River flows during the 1983 irrigation season resulted in the diversion of CBD flows through the ridge cut (State Water Resources Control Board [SWRCB], April 1984) and eventually into Cache Slough in the northern delta (Figure 2). During the irrigation season, outflow from the CBD is generally low in April as rice fields are flooded. Outflow increases from May through August. High outflows during May can occur at times when rice fields are drained to protect the rice levees from erosion due to high north winds. Peak outflows occur in September and October when the rice fields are drained for harvest (UCD, August 1974).

During the rice-growing season, up to one-third of the Sacramento River flow between Knights Landing and Sacramento may consist of rice-field drain water (Department of Fish and Game [DFG], 1983a, and SWRCB, April 1984). The CBD is the largest single source followed by Sacramento Slough on the east side of the river (DWR, November 1966, and UCD, 1980a). During 1950 to 1959, the combined flows of these two drains contributed 56 percent of the agricultural return flows to the river (DWR, November 1966). In the 1980s, these two drains had a combined contribution of 70 percent of the May to September irrigation return flows to the river (DWR, July 1987).

Drainage and flooding problems in the Colusa Basin have received much attention in the past (DWR, 1964; USBR, September 1973; USBR, June 1974; USBR, October 1974; USBR, June 1980; DWR, June 1986; and DWR, September 30, 1987). Winter flooding problems occur in the basin when tributary runoff becomes too great for the canals to handle. Flooding also occurs in the spring when irrigation return flows are too great (USBR, June 1974).

Several solutions to the drainage and flooding problems have been investigated, including: construction of foothill reservoirs on tributary streams,



construction of levees in low-lying areas, enlargement of the Knights Landing Ridge Cut to divert flood flows down the Yolo Bypass to the delta, improved watershed management, diversion of northern basin tributaries to the river, increasing the flow capacity and discharge characteristics of the CBD, pumping water from the CBD to the river, construction of a new drainage canal at a higher elevation, diversion of streams into the Tehama-Colusa Canal for use in Yolo and Solano Counties, construction of flood-retention reservoirs on National Wildlife Refuges, improvement of water and drainage management, establishment of flood easements along the CBD, and diversion of the CBD to the river at a point upstream of Colusa (DWR, 1964; USBR, October 1974; USBR, June 1980; DWR, June 1986; and DWR, September 30, 1987). Any possible alternative to control drainage and flooding in the Colusa Basin needs to take into account the impact of increased flows on flooding and water quality in the delta (USBR, October 1974).

Water quality in the CBD has been investigated by many private and governmental agencies, including: Department of Water Resources, Department of Fish and Game, Department of Food and Agriculture (DFA), Department of Health Services (DHS), State Water Resources Control Board, Central Valley Regional Water Quality Control Board (CVRWQCB), U. S. Bureau of Reclamation, University of California at Davis, the rice industry, Rice Research Board, Stauffer Chemical Company, Chevron Chemical Company, private consultants, and irrigation districts. Much of the work in recent years is related to rice herbicides and sediment production in the basin. Water quality problems in some areas of the basin are due to erosion and leaching of the alkaline soils (DWR, 1964). Water quality in the Sacramento River below Colusa is influenced by agricultural drainage. Significant amounts of suspended sediments, turbidity, dissolved solids, nutrients, and pesticides are discharged to the river from the CBD (DWR, March 1986).

Several factors influence the quantity and quality of agricultural drainage waters in the CBD, including: crop acreages, rainfall patterns, crop cultural practices (especially rice), Sacramento River flows, water district management, and water retention regulations on rice fields (DWR, July 1987). In addition, the Bureau of Reclamation (September 1973) lists increased reuse of water for irrigation, increased irrigation in the basin, increased importation of water to the basin, changes in agricultural practices, increased use of lesser quality ground water, increased wildlife populations, increased recreational use, and future urban and industrial waste loads as factors that could influence water quality in the CBD. The State and Regional Boards (March 1986) identified point sources that can influence CBD water quality. These sources include: wastewater treatment plant effluent from Willows and Colusa, sewage treatment plant effluent from Williams and Maxwell, and food-processing wastes and cooling water effluent from the Glenn Milk Producers Association.



## GENERAL QUALITY

Water temperature in the CBD is usually higher than in the river, particularly during the irrigation season. In addition, river temperatures below the CBD outfall are generally higher than temperatures above the outfall. The U. S. Bureau of Reclamation (September 1973), analyzing data from 1968 to 1971, could not determine whether increased temperatures in the Sacramento River below the CBD outfall were due to thermal loading from the CBD or just due to warming from increased travel time from the station above to below the outfall. Hayes et al. (1978) found that during the summers of 1973 through 1975, CBD water temperatures were significantly higher ( $p < 0.05$ ) by 4 to 5°C than Sacramento River temperatures. Data from 1974 through 1978 (DWR, March 1979) indicated that water temperatures in the CBD followed a seasonal pattern with highs occurring in the late summer and lows in the winter. Temperatures ranged from about 41°F in December 1978 to 87°F in July 1974. Water temperatures in the CBD can fluctuate considerably in a relatively short period of time. During August 1978, temperatures ranged from 71°F to 91°F (UCD, November 1978). Irrigation season temperatures in 1980 and 1981 ranged from 67°F to 79°F (DFG, 1982), while temperatures from April through June 1986 ranged from 63°F to 82°F (DFG, 1986) in the CBD.

Agricultural return waters are usually more basic than the Sacramento River (DWR, 1962). During the summers of 1973 to 1975, the pH of CBD water was significantly higher than the pH of Sacramento River water (Hayes et al., 1978). The CBD pH values for 1977 through 1979 ranged from 7.4 to 8.4 (UCD, December 1981). Values during a peak storm event in January ranged from 7.9 to 8.5. At the beginning of the 1978 irrigation season, water delivered to the Colusa Basin for irrigation had a pH of 7.8, while return flows in the CBD ranged from 8.2 to 8.5 (UCD, November 1978). During the 1980 and 1981 irrigation seasons, pH values in the CBD ranged from 6.8 to 8.1 (DFG, 1982). Data from the Department of Water Resources' Water Data Information System (WDIS) for the 1980s showed a mean pH in the CBD near Knights Landing of 7.9 (range 7.3-8.6). The river above the outfall for the same time period had a mean pH of 7.6 (range 7.2-8.2), while the river below the outfall was elevated slightly with a mean pH of 7.7 (range 7.2-8.4).

Dissolved oxygen (DO) levels in the CBD are normally lower than in the Sacramento River and are often below saturation. Levels were often below 80 percent saturation in the CBD from 1968 to 1971 (USBR, September 1973). During August of 1978, percent saturation values ranged from 72 to 97 percent (UCD, November 1978). Dissolved oxygen concentrations are usually highest during the winter and lowest in the summer and fall. Some exceptions to this pattern can occur during the summer months when high values result from high photosynthetic activity in the late afternoon. Values from 1974 to 1978 in the CBD ranged from 6 mg/L in July 1974 to 14.6 mg/L in March 1974 (DWR, March 1979). Values during the irrigation season have ranged from 5.9 to 9.4 mg/L in 1980 and 1981 (DFG, 1982), from 4.8 to 6.9 in 1982 (DFG, 1983a), and from 5.8 to 9.2 in 1986 (DFG, 1986). During the 1982 irrigation season, DO values were near saturation for the Sacramento River (DFG, 1983a) and ranged from 8.0 to 10.4 during the 1986 season (DFG, 1986). Most of these values are adequate to support fish life within the CBD according to information presented by the Bureau of Reclamation (September 1973) and Department of Fish and Game (1982

and 1983a). It should be noted that during the 1980 and 1981 irrigation seasons, oxygen levels were nearly depleted in the Knights Landing Ridge Cut, with values ranging from 0.9 to 3.0 mg/L (DFG, 1982). Only a minor amount of water is discharged through the ridge cut during the irrigation season. The WDIS data for the 1980s support the findings that DO levels are substantially lower in the CBD than in the Sacramento River. The CBD near Knights Landing showed a mean DO of 8.3 mg/L (range 5.0 to 11.9 mg/L), while the Sacramento River above the CBD had a mean of 9.9 mg/L (range 7.6 to 12.5 mg/L) and the river below the outfall had a mean of 9.8 mg/L (range 7.4 to 12.1/mg/L).

## MINERAL QUALITY

Waters of the CBD have been classified as sodium-magnesium bicarbonate in nature (DWR WDIS, March 1986). The University of California at Davis (1980b) identified sodium, sulfate, and bicarbonate as the dominant soluble ions in the CBD. According to the WDIS data, sodium has normally been the dominant cation and at times has accounted for over 50 percent of the cation concentration in milli-equivalents per liter (meq/L). The bicarbonate ion has been the dominant anion and almost always accounted for over 50 percent of the anion concentration in meq/L. While sodium dominates as the soluble cation in the CBD, calcium and magnesium dominate as exchangeable cations that are adsorbed to suspended sediments in the drain. In contrast, the Sacramento River is calcium-magnesium bicarbonate in nature with substantially lower concentrations of mineral constituents (DWR WDIS, March 1986).

Waters of the CBD are moderately hard with monthly means during the 1980 and 1981 irrigation seasons ranging from 141 to 205 mg/L  $\text{CaCO}_3$ . The CBD waters are alkaline with monthly means ranging from 130 to 226 mg/L as  $\text{CaCO}_3$  for the same time period (DFG, 1981).

Total dissolved solids (TDS) and electrical conductivity (EC) are substantially higher in the CBD than in the river and increase substantially in the river below the CBD (DWR, 1962; DWR WDIS, 1970; Hayes et al., 1978; UCD, November 1978; CVRWQCB, April 1979; and UCD, 1981). According to the Department of Water Resources (November 1966), agricultural drainage is the principal source of increased mineral concentrations in the Sacramento River from Keswick to Freeport. Compared to water delivered to the basin during the irrigation season, water in the CBD reflects higher mineral conditions because of use and reuse for agricultural purposes. Concentrations of salts in the Sacramento River are not a water quality problem in the river itself, but mass loading to the delta from agricultural return flows is a concern of the CVRWQCB (April 1979). During the 1976-77 drought, agricultural return flows made up 10 to 13 percent of the total river flow at Sacramento, while agricultural return flows were responsible for 28 to 38 percent of the salt load (CVRWQCB, April 1979). Highest mineral loading to the Sacramento River from the CBD occurs during the irrigation season, from May to November (DWR, November 1966).

Mineral concentrations as indicated by EC in the CBD are generally lowest during the summer irrigation season (DWR, November 1966, and DWR, March 1979) and tend to increase in a downstream progression within the CBD (UCD, 1980a). Occasionally, low EC's are observed in the winter corresponding to peak storm events (DWR, March 1979, and UCD, December 1981). High EC's tend to correspond to low-flow periods in the winter and spring and may represent leaching of salts that accumulated in the soil during the previous irrigation season (DWR, March 1979). Values for EC can be high at the beginning of the irrigation season for the same reason (UCD, August 1974). A salt balance study conducted in the CBD during 1973 indicated that the TDS load (tons) of water flowing out of the basin increased progressively during the irrigation season over the TDS load of water being delivered to the basin (UCD, August 1974). The overall ratio of tons of salt in CBD outflow to tons of salt in the inflow was 0.65, indicating that 35 percent of the salt entering the Colusa Basin during the 1973 irrigation season was stored within the soil-water system of the basin.

Mid-summer quality in the CBD is generally better, since most of the soluble salts have been leached from the soil (UCD, November 1978). Even with the storage of salts in the basin during the 1973 irrigation season, output to input ratios for EC and TDS concentrations in the CBD were 3.14 and 2.42, respectively. This indicates that the EC in outflow water is being concentrated about three times over the inflow water and TDS is being concentrated nearly two and a half times. This is largely due to the loss of water through evapotranspiration as it is used and reused within the basin, thereby concentrating the salts. The actual outflow to inflow ratio for water during the 1973 irrigation season was 0.27, indicating that nearly three-quarters of the water imported into the basin was consumed via evapotranspiration and possibly stored to ground water recharge.

According to DWR agricultural water quality requirements (Table 1) reviewed by the U. S. Bureau of Reclamation (September 1973), historic data indicates that water in the CBD is almost always Class I (suitable under most conditions) for agricultural purposes (DWR, 1964; DWR, WDIS; and USBR, September 1973). Occasionally, CBD water is Class II (suitability depends on crop and climate) with respect to EC, but these periods usually occur during the nonirrigation season. Water discharged from RD 787 is at times high in boron and may be detrimental to sensitive crops, but this water is well diluted by the CBD (USBR, September 1973).

Most ground water sources in the Colusa Basin are very good quality and Class I for agricultural use. However, the ground water is generally of lesser quality than Sacramento River water delivered to the basin. The Department of Water Resources identified several wells in the Arbuckle area that were Class II (suitable under most conditions) or Class III (mostly unsuitable) for agricultural use with respect to EC, chloride, and boron (DWR Arbuckle Problem Area

Table 1. Irrigation water - qualitative classification  
(from USBR, September 1973)

	EC ( <u>mhos/cm</u> )	TDS ( <u>mg/L</u> )	Cl ( <u>mg/L</u> )	Na <u>%</u>	B ( <u>mg/L</u> )
Class I (suitable under most conditions)	<1,000	<700	<175	<60	<0.5
Class II (suitability depends on crops, climate)	1,000- 3,000	700- 2,000	175- 350	60- 75	0.5- 2.0
Class III (mostly unsuitable)	>3,000	>2,000	>350	>75	>2.0

EC: electrical conductivity  
TDS: total dissolved solids  
Cl: chloride

Na%: percent sodium  
B: boron

Binder). Boron levels ranged from 0 to 12 mg/L with the highest values coming from a deep abandoned well that registered an EC of 43,240  $\mu$ mhos/cm and a chloride concentration of 14,600 mg/L. These data indicate that potential problems could occur in the basin with excessive use of ground water for irrigation. The actual areas where ground water is used should be investigated with respect to quality. In addition, the percent contribution of ground water used in the basin should be investigated to determine if increased ground water use could present a significant threat to surface water quality by increasing salt concentrations in the drain and salt loads to the Sacramento River.

Electrical conductivity of the CBD ranged from 350 to 1,670  $\mu$ mhos/cm for 1953 to 1961. Flow-weighted monthly averages ranged from 417  $\mu$ mhos/cm in July to 1,194  $\mu$ mhos/cm in February (DWR, November 1966). Values for 1974 through 1978 ranged from a low of 240  $\mu$ mhos/cm in April 1977 to a high of 1,430  $\mu$ mhos/cm in March 1974 (DWR, March 1979). During the height of a January storm in 1978, EC ranged from 143 to 437  $\mu$ mhos/cm (UCD, November 1978). At the start of the 1978 irrigation season, values in the CBD ranged from 460 to 1,180  $\mu$ mhos/cm, while the water being delivered to the basin was 195  $\mu$ mhos/cm. During August of 1978, CBD water raised the EC of the Sacramento River by 31  $\mu$ mhos/cm (UCD, November 1978). The WDIS data for the 1980s showed the CBD near Knights Landing to have a mean EC of 619  $\mu$ mhos/cm (range 240 to 1,340  $\mu$ mhos/cm), while the Sacramento River above the outfall had a mean EC of 159  $\mu$ mhos/cm (range 105 to 230  $\mu$ mhos/cm) and the river below Knights Landing had a mean EC of 189  $\mu$ mhos/cm (range 104 to 278  $\mu$ mhos/cm).



## NUTRIENT QUALITY

Nutrient data for the CBD and the Sacramento River above and below the CBD is much more sketchy than mineral data. DWR data dates back to 1957 for the CBD and the river above the CBD (DWR WDIS). The Department of Fish and Game and the University of California at Davis also have some information available.

Nutrient values in agricultural drains for 1969 to 1970 were highly variable, but were generally higher than in the river (DWR, 1970). The University of California at Davis (November 1978) found that nitrogen and phosphorus concentrations in the river were not changed significantly by the CBD outfall in August 1978. Algal biomass in the CBD has shown a positive exponential correlation with orthophosphate concentration ( $r = 0.91$ ) (UCD, 1980b). Total ammonia concentrations ranging from 0.1 to 0.2 mg/L were detected in the CBD in June and July of 1980 and 1981 (DFG, 1982). Values recorded in WDIS for total ammonia plus organic nitrogen and total phosphorus have ranged from 0 to 2.2 mg/L and from 0.06 to 0.46 mg/L, respectively, for the CBD. Values for total ammonia plus organic nitrogen (1980-1988) for the CBD near Knights Landing show a mean of 0.9 mg/L (range 0.5-1.6 mg/L), while values in the river above the outfall had a mean of 0.3 mg/L (range 0.2-1.1 mg/L). Total phosphorus concentrations in the CBD near Knights Landing during the 1980s had a mean of 0.20 mg/L (range 0.11-0.39 mg/L), while concentrations in the river above the outfall showed a mean of 0.08 mg/L (range 0.04-0.32 mg/L). Data below the outfall were not collected and data in the river above the outfall were very sketchy after 1983. The WDIS data indicate that mean concentrations of nitrogen and phosphorus are nearly three times greater in the CBD than upstream in the river.



## SEDIMENTS

Production of suspended sediment in the Colusa Basin and their impact on the Sacramento River have received much attention, particularly by the University of California at Davis (August 1974, November 1978, 1980a, 1980b, 1981, and December 1981). Suspended sediment (SS), turbidity, and color are generally higher in the CBD and result in an increase in the river below the CBD outfall (DWR, 1962; DWR, 1970; Hayes et al., 1978; UCD, November 1978; and DWR, March 1986). Increased turbidity in the river due to the CBD outfall often exceeds the Sacramento River objectives set in the "Central Valley Basin Plan" (CVRWQCB, April 1979) and turbidity in the drain frequently exceeds criteria for municipal use (USBR, September 1973). A turbidity plume is usually evident in the river when the CBD is discharging at Knights Landing (CVRWQCB, April 1979). The annual mean turbidity during 1968 through 1971 was actually lower in the river below the outfall than above (USBR, September 1973). This drop in turbidity was probably due to the closure of the Knights Landing outfall gates during high river flows, when CBD water is diverted through the ridge cut to the Yolo Bypass. The highest levels of turbidity and SS occur during the nonirrigation season with peak storm events (UCD, 1980a; UCD, 1980b; UCD, 1981; and UCD, December 1981). Therefore, the periods when highest turbidity and SS levels occur in the CBD correspond to periods when the CBD may not be discharging to the river at Knights Landing. However, recent data during the 1980s (DWR WDIS) do not support the Bureau of Reclamation findings. Turbidity in the CBD during the 1980s showed a mean of 53 Nephelometric Turbidity Units (NTU's) (range 7 to 567 NTU's) with the river above the outfall having a mean turbidity of 21 NTU's (range 1 to 212 NTU's) and the river below the outfall having a mean of 25 NTU's (range 4 to 198 NTU's). The University of California at Davis (November 1978) found that CBD water generally raised river turbidity by 10 to 20 Jackson Turbidity Units (JTU's). During the 1969 through 1971 irrigation seasons, the mean CBD turbidity of 129 JTU's raised the river turbidity below the outfall to a mean of 38 JTU's from a mean of 28 JTU's above the outfall (UCD, November 1978). In addition, the mean SS concentration in the CBD was 106 mg/L and increased the river SS level an average of 13 mg/L. During 1976 and 1977, agricultural return flows to the Sacramento River accounted for 16 to 22 percent of the SS load at Sacramento (CVRWQCB, April 1979).

Color in the river increases below the CBD outfall, with the maximum increase in late September corresponding to the drainage of rice fields for harvest (UCD, 1981).

Suspended sediments of the CBD are considerably different than those of the river and appear to impact the bottom sediments of the river below the outfall. Bottom sediments in the river above the outfall are gravelly, while those below the outfall are predominated by medium sand (UCD, December 1981). The University of California at Davis (1980a) found that suspended sediments in the CBD were very low in organic content (1.5 to 4 percent). The river had one-fifth the SS concentration as the CBD, but contained twice the organic content. These data were developed in 1978 and 1979 immediately after the drought years. Similar findings were made in 1979 and 1980 (UCD, 1980b). In 1980 and 1981, suspended sediments from the CBD were found to be 60 percent mineral, 10 percent phytoplankton, and 30 percent suspended organic matter

(UCD, December 1981). The discrepancy in percent organic matter observed between the years may be a reflection of the drought years. Suspended sediment concentrations during early 1978 in the CBD were considerably higher than those from previous years (DWR, March 1979). The high SS concentrations in 1978 were probably due to the accumulation of sediments during the previous two drought years. It is possible that the sediments accumulated during the drought were mostly mineral in nature and when flushed during 1978, represented a higher proportion of the SS makeup than in most years.

Significant erosion and sediment production occurs in the CBD with approximately 269,000 tons of soil eroded yearly (UCD, 1980a). Substantially more sediments were produced during the 1977-78 water year (following the drought) when 451,920 tons of sediment were discharged from the CBD during the nonirrigation season. An additional 53,970 tons were discharged in the irrigation season (UCD, November 1978). Three areas of concern have been identified with respect to the source of SS in the Colusa Basin. These include: bare level soils, moderate to steep cultivated soils, and steep noncultivated foothill soils (UCD, 1980a). Careful management of soil cover and grazing on steep noncultivated soils, use of grassed waterways and contour strips on steep cultivated land, and conservation of farm water and recycling on level basin soils were recommended to control sediment production in the basin (UCD, 1980a).

Bed materials in the CBD are a reflection of current velocity and slope. Areas of high velocity generally have coarser material, while areas of low velocity have more fine materials (UCD, 1980a, and UCD, December 1981).

Turbidity and SS tend to increase in a downstream progression in the CBD from Willows to Knights Landing (CVRWQCB, April 1979, and UCD, 1980b). During the 1973 irrigation season, turbidity and SS outflow to inflow ratios were 3.44 and 3.00, respectively. This indicates that water flowing out of the CBD is nearly three and a half times more turbid and three times higher in SS than water imported into the basin (UCD, August 1974).

## TRACE ELEMENTS

Data on trace elements are extremely limited prior to the 1980s and are inconsistent in many cases.

From 1968 to 1971, iron and manganese concentrations often exceeded recommended limits for municipal usage (USBR, September 1973). Copper, lead, selenium, mercury, zinc, cadmium, arsenic, nickel, chromium, iron, and manganese have all been detected in the CBD.

Elevated levels of total copper were detected in the CBD in monthly samples collected between February 1981 and May 1982 (DWR WDIS). Concentrations ranged from 0.02 to 0.04 mg/L and exceeded chronic toxicity levels for the protection of aquatic life (U. S. Environmental Protection Agency [USEPA], 1986) on all but two collection dates. Acute toxicity levels were exceeded in August 1981 and May 1982. It should be noted that these data were for total copper and may have reflected copper bound to suspended matter in the CBD. Data collected between May and November 1985 suggested that the CBD is a major contributor of copper to the Sacramento River (SWRCB and CVRWQCB, March 1986). The CBD nearly always showed higher total copper concentrations than the river. Regional Board data (CVRWQCB, June 17, 1989) collected between December 1986 and April 1987, however, showed total copper values in the CBD (4 to 9  $\mu\text{g/L}$ ) that were nearly always less than values in the Sacramento River near Colusa (8 to 21  $\mu\text{g/L}$ ). State Board data from November 1985 indicated total copper values in the sediments of the CBD and river near Colusa are similar. The results from two separate laboratories conflicted in the sediment analysis for copper with one lab finding higher values in the river and the other finding higher values in the CBD. Copper has also been detected in the flesh of CBD fish but not at levels exceeding any criteria (SWRCB, 1984).

Data collected between February 1981 and May 1982 showed elevated levels for total lead on three dates in the CBD (DWR WDIS). Values ranged from 0.00 to 0.04 mg/L and exceeded chronic toxicity levels to protect aquatic life (USEPA, 1986) in September 1981 and March and April 1982. Lead concentrations were found in CBD sediments in November 1985 and were at higher levels than river sediments near Colusa (SWRCB data, 1985). Lead was also detected in the flesh of CBD fish between 1980 and 1984, but not at levels exceeding any criteria (SWRCB, 1984).

Mercury was below detection limits between May and December 1985 in CBD water and below detection limits for CBD sediments in November 1985 (SWRCB data, 1985). Even though mercury was not found in the water and sediments, levels have been found in CBD catfish between 1979 and 1981 (SWRCB, 1984, and CVRWQCB, March 1987). One fish sample with a value of 0.58 mg/kg in October 1980 exceeded the National Academy of Science guidelines (0.50 mg/kg mercury on a wet weight basis) for the protection of aquatic life and their predators (SWRCB, 1984).

Total selenium values in the CBD between February 1981 and May 1982 ranged from 0.00 to 0.39 mg/L (DWR WDIS). Chronic toxicity standards for the protection of aquatic life (USEPA, 1986) were exceeded in June, July, September, and November 1981 and May 1982. The acute toxicity level for the protection of

aquatic life was exceeded in July 1981. Samples collected by the Regional Board from April 1984 to March 1985 did not support the WDIS data, since only one sample (July 1984, 6  $\mu\text{g/L}$ ) was above the detection limit for total selenium (CVRWQCB, October 1985). High selenium-bearing formations are known to occur in the Coast Range of California (CVRWQCB, October 1985). High concentrations of selenium have been tied to birth defects and death in fish, waterfowl, and other wildlife at Kesterson National Wildlife Refuge in the San Joaquin Valley. In addition, there is an ever-increasing knowledge of potential health hazards of high selenium intake by humans, including infertility, aborted fetuses, and birth defects. Considering the value of the Colusa Basin and its National Wildlife Refuges to migratory waterfowl, and the inconsistent findings for selenium by the Regional Board and DWR, more long-term monitoring may be warranted.

Low concentrations of arsenic, chromium, nickel, and zinc have been detected in CBD waters (SWRCB data, 1985, and CVRWQCB, June 17, 1987) but not at levels to threaten aquatic life. Antimony, cadmium, and tin were below detection limits from May to December 1985 (SWRCB data, 1985). Chromium, nickel, and zinc have been detected in CBD sediments, while cadmium was below detection limits with one laboratory and slightly above for another laboratory in November 1985 (SWRCB data, 1985). Cadmium and zinc have also been detected in the flesh of CBD fish (SWRCB, 1984) but not at levels of any concern.

## PESTICIDES

Pesticides in the CBD were not extensively studied prior to the 1980s. During the mid-1960s, endrin, dieldrin, aldrin, kelthane, and DDT and its breakdown products were detected in aquatic organisms from the CBD (Hunt, 1964; Hunt, 1965; Hunt, 1966; and Hunt, 1967). Levels of these pesticides were lower in the water and sediments of the drain, but were much higher in tissues from catfish, clams, and other organisms. Even though the use of DDT was banned in this country in 1972, levels were still being detected in CBD fish between 1980 and 1984 (SWRCB, 1984). Low levels of DDT and DDE were detected in water samples from the CBD in May of 1987 (CVRWQCB, June 17, 1987).

The U. S. Public Health Service (USPHS) identified a potential for pesticide-related fish kills in the Sacramento River due to increased deliveries of Tehama-Colusa Canal water into the Colusa Basin (USBR, September 1973).

During 1980 through 1984, the following organic chemicals were detected in fish from the CBD: chlordane, dachthal, DDT, dieldrin, endosulfan, alpha HCH (hexachlorocyclohexane), nonachlor, PCB (polychlorinated biphenyls), toxaphene, and chemical group A (the combined concentrations of aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, chlordane, lindane, HCH, endosulfan, toxaphene, and others) (SWRCB, 1984). Dachthal, dieldrin, DDT, chlordane, alpha HCH, endosulfan, PCB, toxaphene, and chemical group A were found at elevated levels when compared to fish from other waters of the State. Toxaphene and chemical group A were the only chemicals to exceed National Academy of Sciences guidelines (100 ppb) for the protection of aquatic life and their predators. During 1980, toxaphene levels were found in two fish at or above the guideline (100 ppb and 200 ppb), while a single fish in 1984 exceeded the standard (450 ppb). One fish in 1980 (249 ppb) and one in 1984 (505 ppb) exceeded the 100 ppb NAS guideline for chemical group A.

Simazine and diazinon were found in February 1987 and endosulfan sulfate was found in May 1987 at low levels in water from the CBD (CVRWQCB, June 17, 1987).

During the 1980s, trihalomethanes (THM) were detected in the City of Sacramento's drinking water (SWRCB and CVRWQCB, March 1986). A study conducted by the Department of Water Resources (July 2, 1987) showed that the CBD had a higher THM formation potential in 1985 and 1986 than did the Sacramento River. In addition, the THM formation potential of the river was higher below the CBD outfall than above, indicating that the CBD could be an important source of THM precursors.

Fish kills (primarily carp) that were documented in the CBD and Reclamation Slough from 1976 through 1983 (DFG, 1982; DFG, 1983a, and DFG, 1983b) were the focus of studies conducted in the early 1980s by the Department of Fish and Game. Fish kills in the two major agricultural drains totaled nearly 30,000 in 1980, 10,000 in 1981, 14,000 in 1982, and 7,000 in 1983. Dissolved oxygen, ammonia, water temperature, ethyl and methyl parathion (organophosphate insecticides), MCPA-DMA (monochloropropionic acid - phenoxy broadleaf herbicide), and copper sulfate (algicide and pesticide used to control tadpole shrimp) were not factors in the fish kills. Evidence indicated that molinate (Ordram), a herbicide used in the control of grassy weeds in rice culture, was responsible

for the fish kills. Fish kills coincided with peak molinate concentrations in the drains. Concentrations approached acute toxicity levels demonstrated to cause anemia and death in carp. In addition, dead fish contained high residues of molinate which were higher than in live fish. Although DO levels in the CBD were adequate to sustain fish life under normal conditions, levels may have been too low at times with the presence of molinate. Anemia in fish, caused by molinate intoxication, may result in a higher oxygen demand for fish.

In addition to molinate, thiobencarb (Bolero) was detected at elevated levels during the Department of Fish and Game studies. On the basis of the DFG findings, it was recommended to develop best management practices to reduce the off-site movement of molinate and thiobencarb and to better define the toxicity of these herbicides to aquatic organisms in California.

Background information was presented by the Department of Food and Agriculture (September 1984) for molinate and thiobencarb. These herbicides are used to control grassy weeds (primarily barnyard grass) in rice culture. Their use became necessary in the late 1970s with the advent of short-stature, high-yielding rice varieties. These short-stature varieties are less capable of competing with grassy weeds that can substantially decrease yield. Propanil is another herbicide that can be used to control grassy weeds in rice, but is not used extensively because it vaporizes and may damage nearby orchards.

Molinate and thiobencarb are usually applied as granules from the air between early May and mid-June. Molinate can also be incorporated into the soil before planting or metered into the rice fields with the irrigation water. Treated water is then released to maintain water levels, to decrease the build-up of wastes that could damage maturing rice, and to prevent damage to levees by high north winds that frequently occur early during the rice-growing season.

Molinate vaporizes rapidly from treated fields. If treated water is held on the field for 8 days, very little molinate remains in solution. Thiobencarb, in contrast, readily adheres to the soil and does not vaporize. It can re-enter field waters when the fields are reflooded. The quantity and concentration of these chemicals discharged to State waters depend on the rate of application, field water retention time, volatility of the chemical, adsorption to sediments, temperature, and type of irrigation practice (SWRCB, April 1984).

During the 1973 to 1975 irrigation seasons, a trace level of molinate was detected only once in the CBD (Hayes et al., 1978). From 1977 to 1982, applications of molinate and thiobencarb more than tripled in the Sacramento Valley (SWRCB, April 1984). Molinate concentrations in the CBD peaked at 374  $\mu\text{g/L}$  for the 1980 and 1981 irrigation seasons (DFG, 1982). During 1982, levels peaked at 700  $\mu\text{g/L}$  in the CBD and 42  $\mu\text{g/L}$  in the river (DFG, 1983a). Efforts to control off-site movement of molinate began in 1983 with the requirement of growers to hold treated water on their fields for 4 days. Peak concentrations reached 139  $\mu\text{g/L}$  in the CBD with much reduced levels in the river (DFG, 1983b). The reduced levels in the river were due to abnormally high river flows that resulted in the closure of the Knights Landing outfall gates. Water from the CBD was diverted down the Yolo Bypass to Prospect and Cache Sloughs (Figure 2). Molinate concentrations near 100  $\mu\text{g/L}$  were detected in Prospect Slough (DFG, 1983b) and levels in the river at

Rio Vista were double those in the upper river (SWRCB, April 1984). In addition, elevated levels were detected in fish of Prospect Slough and molinate levels were detected in the upper reaches of Cache and Lindsey Sloughs. This information suggests that the problems normally occurring in the river below Knights Landing were shifted to the north delta in 1983.

During the early 1980s, the Department of Fish and Game proposed interim water quality guidelines to protect aquatic life from the toxic effects of molinate and thiobencarb (DFG, 1984). The interim guideline for molinate was 90  $\mu\text{g/L}$  and was based on its effect on carp, which appeared to be the most sensitive species. The interim guideline for thiobencarb was 24  $\mu\text{g/L}$ , based on its toxicity to larval striped bass. In 1987, revised guidelines were recommended by the Department of Fish and Game and accepted by the Department of Food and Agriculture to protect aquatic life (DFA, November 1987). The new guidelines recognized that molinate and thiobencarb are additive in their toxicity to larval striped bass and opossum shrimp. The new guideline is a sliding scale ranging from a maximum concentration for molinate of 90  $\mu\text{g/L}$  when thiobencarb concentrations are 0  $\mu\text{g/L}$  to a maximum concentration of 24  $\mu\text{g/L}$  thiobencarb when molinate concentrations are 0  $\mu\text{g/L}$ .

During the early 1980s, thiobencarb was suspected of causing taste problems in the City of Sacramento's drinking water (DFG, September 1984). The Department of Health Services correlated taste problems with a 1.0  $\mu\text{g/L}$  concentration of thiobencarb and recommended treatment of the water with potassium permanganate when that concentration was reached (DFA, September 1984). The Department of Health Services set primary action levels for drinking water at 20  $\mu\text{g/L}$  molinate and 10  $\mu\text{g/L}$  thiobencarb. Primary action levels must be met by public water systems to protect consumers from health hazards. In addition, a secondary action level for thiobencarb of 1.0  $\mu\text{g/L}$  was established to protect consumers from taste problems.

During 1984, the "Rice Herbicide Action Plan" was developed to control off-site movement of molinate and thiobencarb (DFG, September 1984). The program was a cooperative effort by the Department of Fish and Game, the Department of Health Services, the State Water Resources Control Board, the Central Valley Regional Water Quality Control Board, the rice industry, the Rice Research Board, Stauffer Chemical Company, and Chevron Chemical Company, with the Department of Food and Agriculture coordinating. During 1984, growers were required to hold molinate-treated water on their fields for 8 days before release. Concentrations up to 140  $\mu\text{g/L}$  molinate were detected in the CBD, while a peak of 21  $\mu\text{g/L}$  was observed in the river near Sacramento. No fish losses were observed in the CBD, even though concentrations exceeded the criteria to protect aquatic life (DFG, 1984).

The molinate control program in 1985 was identical to 1984 (DFA, November 1987). Molinate levels in the CBD reached 100  $\mu\text{g/L}$  and no fish kills were observed (DFG, 1985). River concentrations were below the primary action level.

The 1986 molinate program added a trigger mechanism. If molinate concentrations exceeded 13.6  $\mu\text{g/L}$  in the Sacramento River, growers were required to hold treated water for an additional 4 days or a total of 12 days on their fields. Growers not discharging to the river or tributaries to the river or growers using approved water management (recirculation or tail-water recovery) did not have to

observe the full 12-day period. In addition, those growers using a preplant application, which results in lower field water concentrations, had to hold water on their fields for only 4 days (DFA, November 1987). Molinate levels in the CBD during 1986 peaked at 88 g/L and levels in the river never exceeded the trigger level. Once again, no fish kills were observed (DFG, 1986).

The 1987 molinate program required treated field water to be held for 12 days, unless the water was not discharged to the river or a tributary to the river. In this case, the holding period was 8 days (DFA, November 1987). Once again, fields using a preplant application had to hold water for only 4 days and fields with tail-water recovery systems were exempt as long as the tail-water was not released for 12 days after molinate application. Peak molinate levels in the CBD were below Department of Fish and Game guidelines and no fish kills were observed. Molinate concentrations were well below the primary action level in the river.

The 1988 molinate program was similar to the 1987 program, except the holding period was increased to 14 days. The 12-day holding period was allowed for growers within water districts using approved water management. In addition, field waters could be released at a rate not to exceed 2 inches over the drain box weir. This was done as an attempt to prevent large volumes of molinate laden water from being released over a short period of time (DFA, November 1987). Concentrations in the CBD were higher than in 1987. The increased concentrations were due to increased use and unseasonably cool weather early in the season. Cool weather decreases volatilization of molinate from the fields (DFA, May 20 to September 9, 1988).

During 1982, thiobencarb concentrations in the CBD peaked at 200 µg/L and reached 12 µg/L in the Sacramento River (DFG, 1983a). A 6-day holding period was required for field water treated with thiobencarb in 1983 (DFA, September 1984). Thiobencarb levels in 1983 were much reduced compared to 1982. Levels in the CBD peaked at 11.3 µg/L, while concentrations in the river were very low (0.8 µg/L). Low river concentrations were due to the unusually high river flows and the diversion of CBD water to the north delta. Concentrations in Prospect Slough reached 5 µg/L thiobencarb and fish were found with concentrations up to 700 ng/g in their flesh.

The "Rice Herbicide Action Plan" (DFA, September 1984) included controls for thiobencarb. Since thiobencarb is more persistent than molinate, restriction of sales was used for control. The 1984 program restricted sales to enough to treat 100,000 acres and required a 6-day holding period. Concentrations in the CBD reached 14 µg/L and the secondary action level for drinking water was exceeded for only one day at the Sacramento River intake for the City of Sacramento (DFA, November 1987).

The 1985 thiobencarb control program took a two-part approach. Certain acreages were exempt from the sales restriction if they did not discharge into the river above the City of Sacramento or used approved water management systems. Nonexempt acreages were required to hold field water for 6 days after treatment (DFA, November 1987). Even so, concentrations of thiobencarb peaked at 19 µg/L in the CBD and exceeded the secondary action level for 19 days at the City of Sacramento's water intake during the irrigation season.

The 1986 program for thiobencarb was similar to the 1985 program, but nonexempt acreages were limited to 20,000 acres (one-third of those treated in 1985). In

addition, there was an overall restriction of sales to enough thiobencarb to treat only 100,000 acres. Concentrations peaked at 7.4 µg/L in the CBD, while the secondary action level for drinking water was exceeded in the Sacramento River for only one day during the irrigation season (DFA, November 1987).

The 1987 sales limitation was for 110,000 acres north of the American River on the east side of the valley and north of Knights Landing on the west side of the valley. These acreages included lands that do not discharge to the river, lands with tail-water recovery systems which were required to hold water for 14 days after application, and lands that through water management did not discharge into the river for at least 30 days following application (DFA, November 1987). No sales limitations were made for acreages south of the American River and Knights Landing, where the field water holding time was 6 days. The secondary action level was not exceeded at the City of Sacramento water intake for the first time since the control program began.

The 1988 thiobencarb program was identical to the 1987 program. Levels in the CBD peaked at 4.5 µg/L and, for the second year in a row, the secondary action level at the City of Sacramento's intake was not exceeded (DFA, November 1987).

Use of bentazon (basagran), another rice herbicide, increased in the mid-1980. Levels up to 16 µg/L were detected in major agricultural drains and the river in 1985 and 1986 (DFG, 1986). It was also detected in finished tap water for the City of Sacramento in 1986 (DFA, November 1987). The Department of Health Services set a primary action level for drinking water of 8 µg/L, which was actually below levels that had been observed in the river. Bentazon was placed on the restricted materials list on June 2, 1987 and was included in the 1987 "Rice Herbicide Action Plan" (DFA, November 1987). The control program required field waters to be held after treatment until the fields were drained for harvest unless the water did not drain into the Sacramento River or its tributaries, the water was retained in a tail-water recovery system until harvest, or the County Agricultural Commissioner authorized an emergency release. In addition, bentazon could not be applied after July 31. River concentrations peaked in mid-September but were below the primary action level.

The 1988 bentazon program was the same as the 1987 program, except lands discharging to the river below Sacramento were exempt (DFA, November 1987). Bentazon use doubled from 1987 to 1988, and concentrations peaked at 5.5 µg/L in the CBD and 0.8 µg/L in the river.

During 1987, the rice herbicide monitoring program was expanded to include the rice herbicide propanil and the carbamate insecticides carbaryl (Seven) and carbofuran (Furadan) (DFA, November 1987). Carbaryl was not detected, while propanil was detected at low levels only once in the CBD. Carbofuran peaked at 13 µg/L in the CBD and reached 2.1 µg/L in the river. No regulatory actions were planned for these pesticides, but further study was planned for carbofuran.

In summary, the rice herbicide issue has received much attention in recent years. Control programs and the cooperation of many private and governmental entities, as well as the rice industry, have resulted in the successful reduction of off-site movement of herbicides. Many of the environmental problems associated with the use of these herbicides appear to be under control.



## AQUATIC BIOLOGY

Algal biomass in the CBD is controlled (in order of significance) by ortho-phosphate, nitrate, ammonia, and temperature. In combination, these four parameters accounted for 99 percent of the variation in suspended algal biomass (UCD, December 1981).

Algal biomass during August 1978 was higher in the supply waters than in the CBD (UCD, November 1978). It was speculated that the biomass in the drain was inhibited by turbidity and possibly minute quantities of herbicides. During the 1973 through 1975 irrigation seasons, diatom density, chlorophyll a, b, and c, and organic matter (as indicated by diatom growths harvested from glass substrates) was significantly lower in the CBD than in the Sacramento River above the CBD (Hayes et al., 1978). Aquatic vegetation in the study area was largely limited to periphyton growths in the upper half meter of the water column (Hayes et al., 1978).

The Department of Fish and Game (1982) noted that during the 1980 and 1981 irrigation seasons, the Knights Landing Ridge Cut was infested with Potamogeton, a rooted aquatic plant. Flows through the ridge cut are normally minimal during the irrigation season, with just enough water to supply the irrigation needs of growers at the end of the cut. Low dissolved oxygen levels were also noted in the ridge cut due to the nearly stagnated water.

The Department of Water Resources (July 1987) noted that some agricultural return flows in the CBD are desirable to maintain adequate water quality for the support of aquatic life and riparian vegetation. Surface waters in the Colusa Basin have generally been adequate for fish and wildlife (USBR, September 1973). Turbidity, however, has often exceeded 50 JTU's, which may be detrimental to fish in the drain. Extensive fish kills in the CBD, documented from 1976 through 1983, were tied to the rice herbicide molinate (DFG, 1982; DFG, 1983a; and DFG, 1983b). A program to control the off-site movement of molinate has been successful in eliminating the fish kills in the CBD since 1984 (DFA, November 1987).

Benthic macroinvertebrates collected by the Department of Water Resources during the 1978 irrigation season were dominated by the asiatic clam (Corbicula manilensis), followed by oligochaete worms and chironomid fly larvae (DWR historic data). Diversity and numbers of organisms were low with only eight species being identified at four stations for two sampling dates in the CBD. Hunt (1966) noted that the primary food item for catfish in the drain was fish. This may have been a reflection of the low density of benthic organisms that were found in the drain.



## SCOPING OF ENVIRONMENTAL ISSUES FOR ALTERNATIVE PROJECTS

Structural alternatives to alleviate drainage and flooding problems in the Colusa Basin that are being evaluated by the Department of Water Resources include: a foothill reservoir plan, a levee and pump plan along the CBD, a plan to increase the capacity of the Knights Landing Ridge Cut, a plan to increase the capacity of the Tule Canal in the Yolo Bypass to divert drainage water out of the CBD, a plan to construct another drainage canal parallel to the CBD, a plan to divert northern CBD flows to the river above Colusa, and a plan to enlarge the CBD itself. Nonstructural alternatives include: improved water and drainage management, establishment of flood easements along the CBD, and channel clearing.

The foothill reservoir plan would dam major tributaries to the CBD to reduce winter flooding. This may impact migratory waterfowl dependent on seasonally flooded habitat. However, more information is needed, determining the amount of seasonal habitat in the basin, and its importance to waterfowl. The plan should benefit water quality in the CBD with respect to suspended sediments and turbidity, particularly during the winter. The reservoirs will trap suspended sediments and turbidity from the drainage area above them, and the more controlled releases should reduce erosion below them. However, much of the suspended sediment load in the CBD comes from bare fields. Sediments carried from foothill tributaries may be important in replacing lost soils from fields when flooded by high runoff levels. Reservoirs are typically heat traps and nutrient exporters. If future consideration is given to construction of these reservoirs, water quality aspects with respect to temperature, minerals, nutrients, and heavy metals should be investigated for each tributary stream. The impacts on riparian vegetation, fisheries, and wildlife within the inundation zone would need addressing.

The levee and pump plan would develop a series of levees along the CBD to prevent flooding. Water trapped on lands inside the levee system would be pumped into the CBD when gravity outflow is not possible. This plan will result in increased channel sediment carrying capacity and could increase sediment export from the Colusa Basin to the Sacramento River and the delta. Water that would normally spill to the floodplain and deposit its sediments would be carried out of the basin. The impact of this increased sediment load on the river and delta would need to be addressed. Any wetland areas dependent on winter flooding along the CBD would be impacted unless, through some mitigation plan, these areas could be flooded periodically. Riparian vegetation along the CBD could be lost during construction of the levee system, unless the levees were set back to maintain the existing riparian zone. Development of seasonal wetlands would benefit migratory waterfowl, if the levee system were set back far enough through a flood easement.

Increasing the capacity of the Knights Landing Ridge Cut would carry higher floodflows from the CBD to the Yolo Bypass to reduce flooding within the basin. This plan could once again result in increased sediment exportation from the Colusa Basin by decreasing over-bank deposition of sediments and could reduce the soil-building processes on lands that normally flood. Mitigation would be necessary if riparian vegetation or wetlands were lost within the cut.

The Yolo Bypass Project alternative would increase the capacity of the Tule Canal in the Yolo Bypass to carry part or all of the CBD agricultural drainage to Prospect Slough in the north delta (Figure 2). The plan would alleviate some drainage problems in the CBD. Benefits could include: water quality enhancement of the Sacramento River from Knights Landing to Rio Vista, use of the drain as an outlet for agricultural return waters from Yolo and Solano Counties, use of the drain as a source of irrigation water, and use of the waters for wildlife enhancement in the Suisun Marsh (USBR, October 1974). In addition, if the warm water from the CBD is diverted down the Yolo Bypass, water temperatures in the river between Knights Landing and Rio Vista may decrease. This could benefit emigrating salmon smolts by decreasing water temperatures from late April through June in the river. Further study would be necessary to determine the impact of CBD water on temperatures in the river. The river near Knights Landing may already be at equilibrium with respect to heat loss and heat gain. If the river is not at equilibrium, then the reduced flows with the diversion of the CBD to the Yolo Bypass may increase the warming rate between Knights Landing and Rio Vista. Potential negative impacts to water diverters, anadromous fish, and resident fish along this reach of river would need to be addressed. In addition, water quality problems in the river associated with the CBD outfall may just be shifted downstream to the delta. This was the case in the 1983 irrigation season when CBD water was diverted down the Yolo Bypass to Prospect Slough due to unusually high river flows. Rice herbicide concentrations in water and fish of Prospect Slough were substantially higher than levels found during normal years (SWRCB, April 1984). Finally, the North Bay Aqueduct has its origin in the north delta at Barker Slough (Figure 2). Any water quality degradation of the north delta by CBD water would have to be addressed and mitigated.

The plan to construct another drain parallel and upslope from the CBD could alleviate some drainage problems and should not substantially impact water quality in the basin.

The plan to divert northern CBD waters to the Sacramento River above Colusa could help to alleviate drainage and flooding problems in the basin. This plan could potentially impact a larger reach of the river than is already affected by the CBD. This reach of river could display increased turbidity, mineral concentrations, nutrient levels, temperature, and other parameters. In addition, the river substrate below the new diversion could be changed, which might impact benthic macroinvertebrate production. The impacts to resident and anadromous fish would need to be addressed as well as impacts to migratory waterfowl if wetland habitat is reduced.

Enlarging the CBD would help alleviate both drainage and flooding problems. As with other structural alternatives, impacts to riparian vegetation along the drain and wetland areas could occur. The increased capacity of the drain would decrease the incidence of flooding, would likely increase the export of sediments from the basin, and could aggravate the loss of seasonal waterfowl habitat in the winter. Finally, more rapid movement of water out of the basin during spring flooding could decrease the time for breakdown of rice herbicides and might result in higher pesticide concentrations in the river.

Improved water and drainage management could be accomplished through development of more recirculation systems to reuse agricultural drainage waters. In

addition, incentives for farmers to hold water on their properties during major storm events could slow runoff into the CBD. Finally, coordinated release of drainage waters could significantly reduce drainage problems. Water management in the form of holding water on fields and coordinated releases should improve water quality with respect to suspended sediments, turbidity, and pesticides. Increased use of recirculation systems will reduce the quantity of water in the drains, but will likely increase the salt concentrations in the return waters. Salt loading in the basin should be addressed.

Establishment of flood easements should have no negative impacts with respect to water quality. It may actually benefit riparian vegetation, wetlands, and wildlife along the CBD. A flood easement would maintain existing seasonal wetlands for waterfowl and could be managed as a refuge.

Channel clearing may result in some minor losses of riparian vegetation. Efforts could be made to minimize those losses. Aquatic life, particularly fish, would be impacted by the loss of cover provided by structures in the channel.



## FURTHER STUDY NEEDS

Several data gaps exist with respect to water quality in the CBD and its impact on the Sacramento River. Mineral analyses have been sketchy in recent years. With the advent of Tehama-Colusa Canal deliveries and the potential for increased deliveries by the Bureau of Reclamation, the impacts on mineral quality of the drain need to be addressed. In addition, nutrient quality information is even more sketchy with very little information on the river below the CBD outfall. More data are needed to determine if there is any impact on the Sacramento River with respect to nutrient loading from the CBD. Trace element data are less available still, and the data that have been collected are inconsistent. More data, particularly with respect to copper, lead, mercury, and selenium, would be valuable for the CBD and the river above and below the CBD.

The impact of the CBD on thermal loading to the Sacramento River would be a valuable study, particularly with respect to the needs of various life stages of anadromous fish. Continuous thermographs could be maintained in the river above and below the CBD outfall and in the outfall itself. In addition, a network of temperature monitoring stations on the river could be maintained to determine where the river reaches equilibrium with respect to heat loss and heat gain. This network would be valuable in determining if the CBD was an important source of thermal loading to the river.

The importance of over-bank deposition of sediments during flooding in the CBD would be a valuable study. If any alternatives to reduce flooding in the Colusa Basin are considered, there will be a need to determine the increase in sediment export from the basin and the loss of soil-building processes in the basin. An inventory of wetlands and the importance of seasonal flooding to migratory waterfowl is needed. Finally, there is a need to determine the impact of greater releases from the CBD on flooding in the Sacramento Valley and delta.

Water management in the basin may lead to increased use of recirculation systems and conjunctive use of more ground water in times of need. A thorough evaluation of ground water quality in the basin and the impacts of its use on surface water quality would be valuable. A study of this nature is needed to determine if the use of lesser quality ground water will affect the beneficial uses of drainage water in the basin and in the river. In addition, the effect of increased recirculation of agricultural drainage waters and conjunctive use should be studied with respect to salt loading in the Colusa Basin. A salt balance study is needed to determine if salts accumulated in the soil-water system of the basin during the irrigation season are effectively leached and flushed out of the basin during the winter and spring. Accumulation of salts in the long run might be detrimental to agriculture in the basin.



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## APPENDIX A

### Annotated Bibliography

1. Central Valley Regional Water Quality Control Board. Irrigation return-flow monitoring, 1976 and 1977. 109 pp. April 1979.

Concentrations of salts in the Sacramento River are not a water quality problem in the river itself, but, due to the mass load from the agricultural drains, may have an impact on the delta. Turbidity of the river increases due to irrigation drainage and frequently exceeds the river objectives set forth in the "Central Valley Basin Plan".

During 1976 and 1977, agricultural return flows made up 10-13 percent of the total Sacramento River flow at Sacramento. In addition, the return flows contributed 28-38 percent of the salt load and 16-22 percent of the suspended sediments.

Irrigation return flows increased salinity in the river during the drought because there was less flow in the river for dilution. Suspended solids, on the other hand, decreased with the drought due to reduced return flows and greater reuse.

Turbidity in Colusa Basin Drain (CBD) tends to increase from near Willows to its outfall at Knights Landing. A turbid plume is usually visible in the Sacramento River below the CBD outfall. Fish and benthic organisms may contribute turbidity in the drain. Drains in areas planted with rice are more turbid than the surface runoffs from rice fields.

2. Central Valley Regional Water Quality Control Board. Draft water quality survey for Selenium in the Sacramento River and its major tributaries. 9 pp. October 24, 1985.

In July, September, and November 1981, and January and March 1982, DWR found total selenium concentrations ranging from 20 to 390  $\mu\text{g/L}$  in the CBD near Knights Landing. These concentrations all exceed USEPA drinking water criteria ( $>10 \mu\text{g/L}$ ). Sampling of the CBD for total selenium during this study (April 1984 to March 1985) produced only one sample above the detection limit (6  $\mu\text{g/L}$  on July 19, 1984).

3. Central Valley Regional Water Quality Control Board. Regional mercury assessment. 31 pp. March 1987.

Mercury has been detected in fish throughout the Central Valley Region. Guidelines set for the protection of aquatic life and their predators at 0.50 ppm have been exceeded in fourteen water bodies including the CBD. Concentrations of mercury in water are usually below the detection limit. Mercury is bio-accumulated. Problems are usually associated with areas of sedimentation (lakes, reservoirs, delta, etc.).

Mercury levels in catfish from the CBD were found in 1979 (0.17-230 mg/kg), 1980 (0.58-215 mg/kg), and 1981 (0.12-300 mg/kg).

4. Central Valley Regional Water Quality Control Board. Results of the 1986-87 pesticide study of the Sacramento River and agricultural drains. Memorandum. June 17, 1987.

Monthly samples were collected from the river and drains for the period of November 1986 through June 1987. The results are in tabular form.

On February 15, 1987, simazine (1.6 µg/L) and diazinon (1.2 µg/L) were detected in the CBD. On May 26, 1987, DDE (0.01 µg/L), DDT (0.02 µg/L), and endosulfan sulfate (0.03 µg/L) were detected in the CBD. Many of the May and June results were still pending at the time of the memorandum.

Monthly analyses for total copper, cadmium, nickel, and zinc are presented for December 1986 through April 1987. Total copper values in the CBD ranged from 4 to 9 µg/L; total cadmium was always below the detection limit; total nickel ranged from <5 to 26 µg/L; and total zinc ranged from 2 to 17 µg/L. It is interesting to note that concentrations of these elements in the river at Colusa during this time period were nearly always higher than the CBD (total copper, 8-21 µg/L; total cadmium, <0.1-0.6 µg/L; total nickel, <5-56 µg/L; and total zinc, 9-71 µg/L).

5. Department of Fish and Game. Colusa Basin Drain and Reclamation Slough monitoring studies, 1980 and 1981. Environmental Services Branch, Administrative Report 82-3. 52 pp. 1982.

Field investigations were conducted to determine the cause of fish losses (primarily carp) in agricultural drains associated with rice culture. The studies were conducted between June and October 1980 and April and September 1981. Documented carp losses in the CBD had occurred since 1976 and may have occurred even earlier. In 1980 and 1981, it was estimated that 30,000 and 10,000 fish, respectively, were killed between late May and early June in the CBD and Reclamation Slough.

Dissolved oxygen, ammonia, water temperature, ethyl parathion, methyl parathion, and MCPA-DMA were not factors in the fish losses. The herbicide molinate (Ordram) may have approached acute toxicity levels for fish in the drains and was present at chronic toxicity levels, which have been demonstrated to cause anemia and death in carp. The fish losses in 1980 and 1981 coincided with peak molinate concentrations (up to 374 µg/L), and dead fish contained residues of molinate. It was concluded that molinate was the cause of annual fish kills in the CBD and Reclamation Slough.

Colusa Basin Drain and Reclamation Slough waters were moderately hard (monthly mean, 141-205 mg/L CaCO<sub>3</sub>), alkaline (monthly mean, 130-226 mg/L CaCO<sub>3</sub>), with pH's ranging from 6.8 to 8.1. Total ammonia was only detected in June and July (0.1 and 0.2 mg/L). Monthly mean water temperature ranged from 19 to 26°C, while dissolved oxygen levels ranged from 5.9 to 9.4 mg/L except in the Knights Landing Ridge Cut, where the monthly mean ranged from 0.9 to 3.0 mg/L. Water flow in the ridge cut was minimal during the study and the channel was infested with Potamogeton sp.

Recommendations included: expanding monitoring studies to the river and other agricultural drains in 1982, to better define molinate toxicity to California

aquatic organisms, to develop best management practices to curtail off-site movement of molinate, and to conduct similar studies on thiobencarb (Bolero).

6. Department of Fish and Game. Rice herbicide concentrations in Sacramento River and associated agricultural drains, 1982. Environmental Services Branch, Administrative Report 83-5. 34 pp. 1983a.

This study was conducted between May and July 1982 to determine water quality and rice herbicide (Ordram and Bolero) concentrations in the Sacramento River and major agricultural drains. Detectable levels of molinate and thiobencarb were found in drain waters between the second week in May and the first week in July 1982. Concentrations up to approximately 700 µg/L molinate and 200 µg/L thiobencarb were found in the CBD in early June. Rice herbicides were detected in the river from mid-May to late June 1982 (up to 42 µg/L molinate and 12 µg/L thiobencarb), with molinate being present for 3 weeks longer than thiobencarb. During the first week of June, a fish kill of about 13,000 carp and 1,000 channel catfish occurred in the CBD corresponding to the peak rice herbicide concentrations. Dead fish had higher residues of the herbicides than did live fish. Bioconcentration factors for skeletal muscle of fish ranged from 1 to 24 X for molinate and 9 to 311 X for thiobencarb.

There was no detectable off-target movement of copper sulfate (an algicide) into waters of the agricultural drain and was therefore not a factor in the fish kills.

During low to normal Sacramento River outflow years, discharges from agricultural drains may contribute up to one-third of the river flow above the confluence of the Feather River.

Dissolved oxygen was near saturation in the Sacramento and Feather Rivers, while levels ranged from 4.8 to 6.9 mg/L in the lower CBD. While oxygen levels in the drains were high enough to sustain fish life under normal conditions, when molinate is present (causing anemia in fish), the fish may require higher oxygen levels than in uncontaminated waters.

7. Department of Fish and Game. Rice herbicide concentrations in Sacramento River and associated agricultural drains, 1983. Environmental Services Branch, Administrative Report 83-7. 57 pp. 1983b.

Concentrations of rice herbicides in water and fish of the Sacramento River and associated agricultural drains were investigated between November 1982 and July 1983. In addition, the hematology of fish in the CBD was investigated.

Molinate and thiobencarb were detected between the third week of May and the second week of July 1983. Concentrations up to 139 µg/L molinate and 11.3 µg/L thiobencarb were found in the CBD in early June. Herbicide levels were lower in 1983 in both the river and the drains than in previous years. Reduced levels in the drains were attributed to reduced use of the pesticides in 1983 and longer holding time requirements on the rice fields. Reduced herbicide levels in the river were because the CBD did not discharge at Knights Landing during the 1983 irrigation season due to the exceptionally high level of the river. Instead, the CBD was diverted through the Yolo Bypass to Prospect and

Cache Sloughs and eventually into the Sacramento River above Rio Vista. Over one-third of the total volume of rice return water in the Sacramento River originates from the CBD.

An estimated 7,000 carp were killed in the CBD in mid-June, coinciding with peak molinate and thiobencarb concentrations. Live fish collected at the time of the fish kill showed signs of anemia, indicating that molinate was probably responsible. Herbicide residues in CBD fish were present from May 21 to July 24, 1983. Estimated bioconcentration factors for CBD fish ranged from 5 to 20 X and 58 to 535 X for molinate and thiobencarb, respectively. Maximum residues in CBD fish were 1,800 ng/g molinate and 4,000 ng/g thiobencarb.

Generally, the highest residues were found in channel catfish followed by white catfish and then carp.

Concentrations of 100 µg/L molinate and 5 µg/L thiobencarb were detected in Prospect Slough in mid-June, while 10 µg/L molinate and 0.5 µg/L thiobencarb were detected in the river near Rio Vista.

Residues of molinate and thiobencarb (maximums 1,000 ng/g and 700 ng/g, respectively) were detected in fish collected from Prospect Slough on June 20, 1983.

8. Department of Fish and Game. Rice herbicide concentrations in the Sacramento River and associated agricultural drains, 1984. Environmental Service Branch, Administration Report 84-4. 35 pp. 1984.

Concentrations of molinate and thiobencarb in water and fish of the Sacramento River and associated agricultural drains were determined between April and June 1984. Both herbicides were detected between April 25 and June 27, 1984 at concentrations in the CBD up to 140 µg/L molinate and 14 µg/L thiobencarb. Herbicide levels were slightly lower than in 1983 and much lower than in 1981 and 1982. No fish losses were observed in the drains in 1984. Detectable levels in fish from the drains ranged from <100 to 270 ng/g molinate and <100 to 280 ng/g thiobencarb. Interim water quality guidelines (90 µg/L molinate and 24 µg/L thiobencarb) for the protection of aquatic organisms appeared to protect fish. The primary objective of this study was to document the relative success of the Department of Food and Agriculture's 1984 "Rice Herbicide Action Plan" in reducing the off-target movement and adverse effects of rice herbicides. Concentrations of molinate (peak 21 µg/L) in the river were greater than those in 1983, but less than those in 1982. Thiobencarb showed a similar trend in the river with a peak in 1984 of 1.0 µg/L. It should be mentioned that the 1983 river concentrations were low because the CBD did not discharge into the river at Knights Landing that year.

9. Department of Fish and Game. Rice herbicide concentrations in the Sacramento River and associated agricultural drains, 1985. Environmental Services Branch, Administrative Report 85-2. 39 pp. 1985.

The investigation was conducted between April and June 1985 to determine Ordram (molinate) and Bolero (thiobencarb) concentrations in the Sacramento River, associated agricultural drain waters, and fish.

Both rice herbicides were detected between April 26 and June 26, 1985, with concentrations up to 100 µg/L molinate and 19.0 µg/L thiobencarb being found in the CBD. Molinate levels were slightly lower in 1985 than in 1984, while thiobencarb concentrations were two to three times greater in 1985 than 1984. No fish losses were observed in 1985. Molinate and thiobencarb residues in fish ranged from <50 to 200 ng/g and from 50 to 3,200 ng/g, respectively.

No carbofuran (a preplant insecticide) was detected in either the drains or the river.

10. Department of Fish and Game. Rice herbicide concentrations in the Sacramento River and associated agricultural drains, 1986. Environmental Services Division, Administrative Report 86-2. 28 pp. 1986.

This study was conducted between April and June 1986 to determine molinate and thiobencarb concentrations in the Sacramento River and agricultural drain waters and fish. Molinate was detected between May 5 and June 30, 1986 at concentrations up to 88 µg/L in the CBD. Concentrations of thiobencarb were detected in the CBD between May 19 and June 30, 1986 and peaked at 7.4 µg/L. Molinate and thiobencarb residues in fish from the CBD ranged from 110 to 820 ng/g and from 340 to 3,800 ng/g (fresh weight), respectively. No fish kills were observed for the third consecutive year.

Pesticide use data indicated an increased use of copper sulfate to control tadpole shrimp in rice and bentazon for weed control in rice. Bentazon was detected in the river and drains in 1985 and 1986. Future monitoring for bentazon and copper was recommended.

Pesticides that were previously determined to have minimal off-target movement into drainage water were parathion, methyl parathion, Furadan, and MCPA.

The 90 µg/L guideline for molinate to protect aquatic resources was designed to eliminate carp kills in the agricultural drains, while the 24 µg/L guideline for thiobencarb was designed to protect aquatic invertebrates and larval striped bass in the river.

The 1986 rice herbicide monitoring study was a cooperative effort by the Department of Fish and Game, State Water Resources Control Board, Regional Water Quality Control Board's Central Valley Region, rice industry, Rice Research Board, Stauffer Chemical Company, and Chevron Chemical Company, with the Department of Food and Agriculture coordinating.

Dissolved oxygen concentrations ranged from 5.8 to 9.2 mg/L for the CBD near Knights Landing between April 28 and June 30, 1986. Dissolved oxygen levels in the river near Sacramento ranged from 8.0 to 10.4 mg/L for the same period. Temperatures in the river, for the same period, ranged from 16.2 to 24.0°C near Sacramento, while the CBD near Knights Landing showed a range of 17.0 to 26.8°C.

11. Department of Food and Agriculture. Reducing off-site movement of molinate and thiobencarb from California rice fields, 1984 (draft). 23 pp. September 1984.



12. Department of Food and Agriculture. 1986 program to prevent off-site movement of rice herbicides from California rice fields (draft). 37 pp. October 10, 1985.

Pertinent information is covered in the 1988 report.

13. Department of Food and Agriculture. 1988 program to prevent off-site movement of pesticides from California rice fields (draft). 57 pp. November 18, 1987.

Efforts to control the discharge of pesticides used for rice production in California began in 1983. The herbicides molinate (Ordram) and thiobencarb (Bolero) in agricultural drains occurred at concentrations that were detrimental to beneficial uses. Molinate concentrations in the agricultural drains, including the CBD, were tied to extensive fish kills (primarily carp) in the early 1980s. Thiobencarb concentrations in the Sacramento River were correlated with taste complaints received by the City of Sacramento, whose water supply originates from the river.

The DFG recommended maximum concentrations of 90 ppb for molinate and 24 ppb thiobencarb to protect aquatic life. The Department of Health Services developed primary action levels for protection of water consumers at 20 ppb molinate and 10 ppb thiobencarb and a secondary action level of 1 ppb for thiobencarb to protect consumers from taste problems.

Molinate has been shown to be a relatively short-lived material in rice fields, dissipating rapidly due to volatilization. In 1984, rice growers were required to hold molinate-treated waters on their fields for at least 8 days to allow dissipation. Concentrations of molinate in the agricultural drains in 1984 were slightly higher than DFG guidelines, but no fish kills were observed. Concentrations in the Sacramento River were well below the primary action level.

The 1985 molinate program was the same as 1984, and again no fish kills were observed in the CBD, even though DFG guidelines were exceeded slightly. Maximum concentrations in the river at Sacramento were below the Department of Health Services primary action level.

In 1986, if molinate concentrations in the river exceeded 13.6 ppb, growers were required to hold water on their fields for an additional 4 days or a total of 12 days. Certain growers and areas were exempted from the longer holding period. Growers in regions that did not discharge into the Sacramento River or its tributaries upstream from the City of Sacramento or in areas with approved water management systems did not have to observe the full 12-day holding time. Those growers using a preplant application of molinate, which results in field water concentrations far below those found in aerial-treated fields, were only required to hold their field water for 4 days. Observed levels of molinate in the drains were below DFG guidelines in 1986, and no fish kills were observed. River concentrations never exceeded the 13.6 ppb trigger level.

In 1987, all water treated with molinate had to be held within the field for 12 days unless: the water was not discharged into the Sacramento River, then the holding period was 8 days; the field was treated with molinate as a

preplant incorporated application, then the holding period was the minimum on the Ordram label; or the water was contained in a tailwater recovery system, then the tailwater could be released 12 days after application. Peak molinate concentrations in the CBD were well below DFG guidelines, and concentrations in the river were well below the primary action level established by the Department of Health Services. No fish kills were observed.

The 1988 program was similar to the 1987 program except the holding time was increased to 14 days instead of 12. In addition, acreages within the bounds of an appropriate water agency that used approved water management programs when discharging waters to the river or its tributaries could discharge field water 12 days after application. The final difference in 1988 was restricting field water release volumes to not exceed 2 inches of water over a drain box weir. This provision was to help prevent the release of large volumes of molinate-laden water over a short period of time.

Thiobencarb (Bolero) is a more persistent compound in rice fields where it adsorbs to soil and can repartition back into field water. Therefore, a reduction in use was thought to be the best approach to reduce thiobencarb levels in the drains and river. In 1984, Bolero sales were restricted to enough to treat 100,000 acres and a 6-day post-treatment holding period was required. As a result, the Department of Health Services' secondary action level of 1 ppb was exceeded slightly on only one day at the City of Sacramento's intake.

In 1985, the sales limitation had a two-tier approach. Certain acreages were exempt if they did not discharge into the river above Sacramento or if they used approved water management practices. The remaining nonexempt acreages were required to hold field water for 6 days after treatment with Bolero. Concentrations of Bolero in the river and drains were nearly double those in 1984, and the 1 ppb secondary action level was exceeded for 19 days at the City of Sacramento's intake.

The 1986 thiobencarb program was similar to the 1985 program, except the nonexempt acreages were limited to 20,000 acres (61,000 were treated in 1985), and there was an overall sales limitation to treat 100,000 acres.

The secondary action-level at Sacramento was exceeded on only one day.

Bolero sales in 1987 were restricted to enough to treat 110,000 acres north of the American River and north of Roads E10 and 116 in Yolo County. These acreages included geographic regions that did not discharge into the Sacramento River, land where treated field water was contained in a tailwater recovery system to be held for at least 14 days, and other land that did not drain treated water into State waters for at least 30 days following application. No sales limitations for Bolero were required for acreages south of the American River and roads E10 and 116 in 1987. Field water treated with Bolero on these acreages had a 6-day holding requirement. The 1987 thiobencarb program resulted in the first year that the secondary action level was not exceeded at Sacramento.

The 1988 thiobencarb program was identical to the 1987 program.

The Regional Water Quality Control Board detected the rice herbicide bentazon (Basagran) in finished tap water at Sacramento during 1986. The Department of Health Services recommended a primary action level of 8 ppb, which was below actual concentrations detected in the Sacramento River.

On June 2, 1987, bentazon was placed on the restricted materials list, and a bentazon program was developed. Water could not be released from rice fields at the time of bentazon application. Field waters treated with bentazon had to be retained on the fields until drained for harvest, unless: the water did not drain into the river above Sacramento, the water was contained in a tailwater recovery system until the fields within the system were drained for harvest, or the County Agricultural Commissioner authorized an emergency release. In addition, bentazon was not to be applied to rice fields after July 31 of each year. In 1987, peak bentazon concentrations were found in mid-September and were well below the Department of Health Services' primary action level. The City of Sacramento did not detect bentazon.

The 1988 bentazon program was the same as in 1987, except fields located in basins discharging to the river below Sacramento were exempt.

In 1987, the monitoring program was expanded to include propanil, carbaryl (Sevin), and carbofuran (Furadan) that are additional pesticides used in rice culture. Carbaryl was not detected in either the river or the CBD. Propanil was detected only once in the CBD at 1.6 ppb and not at all in the river. Carbofuran peaked at 13 ppb in the CBD and 2.1 ppb in the river.

On the basis of the 1987 monitoring, no regulatory actions were planned for the use of propanil and carbaryl on rice in 1988. No additional regulatory action was planned for carbofuran in 1988. The Department of Food and Agriculture was to conduct research on the discharge of carbofuran from fields planted with other crops as well as rice.

The DFG recommended revised guidelines for the protection of aquatic life, recognizing that molinate and thiobencarb are apparently additive in their toxicity to immature fish and aquatic invertebrates. The Department of Food and Agriculture accepted the guidelines.

14. Department of Food and Agriculture. Rice herbicide program update. Series of updates. May 20, 1988 to September 9, 1988.

This was a series of newsletters that updated the presence of rice pesticides in surface waters in the Sacramento Valley during 1988. The program was designed to control Ordram, Bolero, and Basagran in agricultural drainage water and the Sacramento River.

Concentrations of Ordram in the CBD peaked at 67 ppb near Knights Landing and 89 ppb 38 miles upstream from Knights Landing.

Flows were very low in the river this year, reducing the ability of the river to dilute contaminants entering from the drains. Even with the low flows, the peak molinate concentrations for the river at the City of Sacramento intake was 4.8 ppb, and was well below the Department of Health Services' primary action level of 20 ppb.

Ordram concentrations in 1988 were higher in the CBD than in 1987. The higher concentrations may have related to increased use by over 60,000 acres in the Sacramento Valley in 1988. In addition, the weather early in the season was unusually cool, which may have reduced the dissipation of Ordram through volatilization.

Bolero application in the valley was also up in 1988 over 1987 by over 10,000 acres. Concentrations in the CBD at Knights Landing peaked at 4.5 ppb, and at the intake to the City of Sacramento, the peak concentration observed was 0.21 ppb.

Basagran use in 1988 lagged behind applications in 1987 due to the cool weather early in 1988. However, near the end of the season, Basagran use had over doubled the 1987 applications, with over 120,000 more acres being treated in 1988. The peak Bentazon concentration for the CBD was 5.5 ppb on July 4 and was detected in the river at 0.8 ppb on September 12.

Propanil had only one positive find in 1988 and was detected in the CBD at 1.1 ppb. Results of carbaryl (Sevin) monitoring were not available at the time of this review.

15. Department of Water Resources. Sacramento River water pollution survey. Bulletin 111. 100 pp. 1962.

The objectives of this survey were to: (1) determine base-line quality conditions for the Sacramento River from Shasta Dam to Mayberry Slough; (2) determine sources of water quality degradation at that time; (3) establish a water quality monitoring program; and (4) recommend future studies and water quality management practices for the Sacramento River. The study was conducted from April 1960 through June 1961.

The river had a mean pH of 7.3, with tributaries and agricultural return waters being somewhat more alkaline.

Suspended solids, turbidity, and color are low at Keswick Reservoir, but increase downstream due to irrigation returns, waste discharges, and algal production in the middle and lower reaches.

Specific conductance (EC) and total dissolved solids are lower in the spring months due to snowmelt. During the balance of the year, irrigation return water increases EC.

16. Department of Water Resources. Colusa Basin investigation. Bulletin 109. 112 pp. 1964.

The Colusa Basin is principally an agricultural area, but also is valuable as wildlife habitat. The soil is of poor quality, both in texture and alkalinity, restricting crops to primarily rice and pasture.

Frequent flooding occurs from tributary runoff and precipitation within the basin.

Water quality problems were identified in some areas due to leaching from alkali soils.

Recreation in the form of pheasant and waterfowl hunting is one of the principal resources identified.

The report lists four possible solutions:

1. A system of reservoirs in the foothills to intercept and store the winter floodwaters.
2. A system of levees in the low-lying areas along the CBD and Willow Creek, with pumping plants and flap gates to drain the flood-prone areas.
3. A scheme to enlarge the drainage system from the toe drain of the Sacramento Ship Channel up to the CBD, especially the Knights Landing Ridge Cut. This was called the Yolo Bypass Project.
4. Watershed management

The report concluded that only the Yolo Bypass Project was economically feasible. However, the levee and pump scheme was conceded to be the best plan from an engineering point of view.

17. Department of Water Resources. Predicted 1990 mineral quality of water in the Sacramento River with emphasis on the effects of agricultural drainage. Office Report. 31 pp. November 1966.

Agricultural drainage was identified as the source of the greatest increase in mineral concentrations for the Sacramento River between Keswick and Freeport. During 1950-59, the CBD and Sacramento Slough contributed 56 percent of total return flows to the Sacramento River. The CBD has a total drainage area of 1,560 square miles. The CBD is the largest individual drain discharging to the river. During high flows, portions of the water are diverted to the Yolo Bypass. During the irrigation season, most of the flow is discharged to the river at Knights Landing. In 1960, about 274,600 irrigated acres contributed flow to the CBD.

Electrical conductivity in the drain from 1953 to 1961 varied from 350 to 1,670  $\mu\text{mhos/cm}$ . Weighted monthly averages ranged from 417  $\mu\text{mhos/cm}$  in July to 1,194 in February. Highest mineral loading occurred from May through November. Highest EC values occur in the winter.

It was predicted that 391,000 irrigated acres would occur in the CBD drainage area in 1990.

18. Department of Water Resources. Sacramento River water quality study, 1969-70. Part II: Present water quality. Memorandum Report. 55 pp. 1970.

This was a one-year study to determine the impact of future expansion of irrigated agriculture on the quality of water in the Sacramento River. It was conducted from August 1969 through June 1970 to determine the water quality of the river and agricultural drains.

Sixteen stations (four on the Sacramento River, one on the Feather River, and the remainder on drains, sloughs, or canals) were sampled twice each month. The data collected include date, time, temperature, flow, pH, electrical conductivity, turbidity, ammonia plus organic nitrogen, nitrate, orthophosphate, and total phosphorus. The turbidity levels were generally higher in the drains than in the river.

Nutrient values in the drains were highly variable but were generally greater than those found in the river.

Water discharged from tributary drains showed higher EC than the river. However, EC patterns for each drain did not display strong similarities.

19. Department of Water Resources. Letter to D. E. Kienlen, Sacramento Valley Water Quality Committee. 60 pp. March 1, 1979.

Data are presented for 15 stations in the Sacramento Valley from October 1, 1977 to December 31, 1978. Included were flows, temperature, pH, dissolved oxygen (DO), specific conductance (EC), suspended solids, and total dissolved solids in tabular forms. Also included were graphical representations of data from January 1974 to December 1978 for discharge, EC, DO, temperature, and suspended solids.

Some of the stations included: CBD at Knights Landing, Reclamation District 108, Yolo Bypass below Sacramento Bypass, CBD at Highway 20, Sacramento River above CBD, and Sacramento River below Knights Landing.

Suspended solids concentrations for early 1978 exceeded those found in the past. The increase was attributed to heavy accumulation of sediments in the drought years, with flushing during early 1978.

Discharge in the CBD near Knights Landing ranged from a high of 3,330 cfs in January 1974 to no flow for several months during the drought of 1976 and 1977. Discharge was generally highest during winter storm periods and irrigation periods. Water temperature followed a predictable pattern of being highest in the late summer and lowest during the winter. Temperatures ranged from about 5°C in December 1978 to near 30°C in July 1974. Dissolved oxygen was generally highest in the winter and lowest in the summer and early fall. Occasionally, DO peaks were observed during the summer months and probably reflected higher photosynthetic activity late in the afternoon. Levels for DO ranged from 6 mg/L in July 1975 to 14.6 mg/L in March 1974. Values for EC were usually higher in the winter and spring than during the irrigation season. Occasionally, EC values, however, were very low during the winter and probably corresponded to peak storm events. The lowest EC value observed (240 µmhos/cm) was in April 1977 and corresponded to very low flows. This data point does not follow the general trend. Other lows (500 µmhos/cm in January 1974 and 275 in January 1978) corresponded to peak runoff events. The highest EC observed was about 1,430 µmhos/cm in March 1974 and corresponded to reduced flows after

2 months of high flows. The high EC's during reduced flow periods of the winter and spring may reflect leaching of accumulated salts from the soil.

20. Department of Water Resources. Sacramento River water quality and biology (Keswick Dam to Verona), a literature review. 100 pp. March 1986.

The Colusa Basin lies west of the Sacramento River and is primarily a rice-growing region due to poor quality soils (texture and alkalinity). The CBD conveys flood runoff and irrigation return flows from about 1 million acres of watershed. The drain is one of the two largest sources of agricultural return flows to the Sacramento River and discharges to the river near Knights Landing.

Water quality in the Sacramento River from Colusa to Verona is influenced by agricultural drainage. Many problems in the CBD are due to erosion and leaching from highly alkaline soils. Significant quantities of suspended sediments, turbidity, dissolved solids, electrical conductivity, nutrients, and pesticides (in some cases) are discharged to the river via the CBD. The University of California, Davis, estimated that 269,000 tons of soil are eroded yearly in the Colusa Basin. Suspended sediments in the drain were highest during the nonirrigation season and were associated with peak storm events.

Historic DWR data from the 1960s classified CBD waters as sodium-magnesium bicarbonate in nature, while University of California, Davis, in 1980 identified sodium, sulfate, and bicarbonate as the dominant soluble ions. During the mid-1960s, high concentrations of DDT and its breakdown products were found in the flesh of CBD catfish and clams, while DDT levels in the water and sediments were low.

The CBD contains high concentrations of suspended sediments that increase river turbidity below the outfall at Knights Landing. The river contains one-fifth the suspended sediments concentration as the CBD, while having two times the organic content. While suspended sediments and turbidity values are highest in the river immediately below the CBD outfall, they decline to levels slightly above those found in the river above the CBD as the river moves downstream. Color also increases in the river below the CBD outfall, particularly during late September with the increased drainage from the rice fields and the resultant increase of organic matter in the drainage water. Electrical conductivity in the river below the CBD outfall shows a similar trend as turbidities.

Diatom density, chlorophyll a, b, and c concentrations, and organic content were significantly lower in the CBD and in the river below the CBD outfall than in the river above the outfall. With further movement downstream, however, the parameters steadily increased to levels slightly below the river above the outfall.

21. Department of Water Resources. Sacramento River trihalomethane study. Memorandum. 5 pp. July 2, 1987.

Samples collected between November 1985 and June 1986 were analyzed for trihalomethane (THM) formation potential at eight stations (five stations on the Sacramento River from Balls Ferry near Anderson to Elkhorn Ferry near

Sacramento, one station on the Feather River, and two stations on agricultural drains). The CBD and Sutter Bypass showed higher potentials for THM formation than did the river stations. The chloroform formation potential increased in the river below the CBD and Sutter Bypass, indicating that the agricultural drainage waters are increasing the THM formation potential of the river.

22. Department of Water Resources. Sacramento Valley rice irrigation study, December 1984. 107 pp. July 1987.

This report examines valley-wide rice irrigation and drainage water movement to see if changes in the drainage system might help reduce herbicide contamination. Also investigated were on-farm irrigation practices and farm or irrigation district recycling to reduce contamination.

Increased drain recapture at a district level would help with herbicide dissipation by increasing the travel time of drain water back to the river.

In 1982 and 1984, during the rice herbicide application period (May and June), about 25 percent of summer irrigation drainage entered the Sacramento River. Some spills to the agricultural drains are desirable to maintain adequate water quality to support aquatic life and riparian vegetation in the drain.

Drainage recycling systems will probably not expand voluntarily because of energy use and costs.

The two major drains (the CBD and Sutter Bypass) combined contribute 70 percent of the May-September irrigation return flows to the river. Seventy-five percent of the water delivered for agriculture is lost to evapotranspiration. Additional studies should be made to see if large quantities of agricultural drainage can be used to meet present and future water demands in Yolo and Lake Counties.

Study area 1 for the report included the rich rice-growing area from Hamilton City to Knights Landing and had more than 450,000 acres of irrigated land in 1982. Irrigation water is supplied by the Tehama-Colusa Canal, diversions from the river, diversions from small westside streams, and ground water augmentation. Return flows occur through the CBD, Reclamation District 108, and Reclamation District 787, and a small amount passes through the Knights Landing Ridge Cut into the Yolo Bypass for irrigation. During the 1982 rice herbicide application period, almost 80,000 acre-feet of water containing herbicides was discharged to the river via the CBD. The acreage planted to rice, rainfall pattern, water depth in rice fields, Sacramento River flows, district management, and water retention regulations were all factors regulating the quantity and quality of agricultural drainage.

23. Department of Water Resources. Arbuckle problem area. Northern District Water Quality and Biology Section. Data binder.

Most of the material in this binder is devoted to the problems of boron in ground water near Arbuckle in the Sacramento Valley. Some surface water information is presented for several streams and State Water Quality Monitoring Program Station 87 in the area. A list of stations, descriptions, locations, and source is found under the "Surface Water" heading. Most of the information is from 1952 through 1961.

Colusa Trough water was classified as sodium-magnesium bicarbonate and occasionally Class 2 for irrigation (due to high conductivity). Hardness ranged from slightly to very hard. During the irrigation season, the water reflects high mineral conditions, since it is used and reused for agricultural purposes.

Boron concentrations in wells of the area sampled in June and July 1968 ranged from 0.0 mg/L to 12.0 mg/L. Most values, however, were below 2.0 mg/L. The 12.0 mg/L value came from a deep abandoned well that had an EC of 43,240 mhos/cm and a chloride concentration of 14,600 mg/L. Many wells in the area were Class II and, at times, Class III for agricultural use with respect to EC, chloride, and boron.

24. Department of Water Resources. Colusa Basin Drain. Water Quality and Biology Section. Data binder. 1978.

Presented are the results of biological monitoring conducted at five stations within the Colusa Basin and two stations on the Sacramento River. Data were collected between August 1 and August 3, 1978 and between October 31 and November 2, 1978.

These data were presented in the University of California, Davis, Water Science and Engineering Paper 4016 (November 1978).

25. Department of Water Resources. Colusa Basin Drain maps and graphs. Northern District Water Quality and Biology Section. Data binder. September 1975-April 1976.

A graphical presentation of data collected from 16 stations within the CBD is shown for electrical conductivity, turbidity, sulfate, and chloride (September 1975 to April 1976). These data are also presented on schematic line maps of the basin for each date of collection.

Both graphical and tabular records of discharge for the CBD at College City and Highway 20 are found loose in the binder (October 1975 to January 1977). Highest flows were observed in May, August, and September. Highest conductivities corresponded to lower flows from December 1975 through February 1976.

26. Department of Water Resources. WDIS (Water Data Information System) data for the CBD and the river.

Data from WDIS was looked at for four stations. The Colusa Basin Drain at Knights Landing (surface water station AO-2945.00) is located at the Knights Landing outfall gates. Mineral data ranged from June 1957 through August 1984. The best records ranged from June 1957 through June 1961, with EC data available from August 1961 through June 1962 and sketchy information thereafter. Nutrient data were very limited with data available from July 1957 through April 1965. The most complete nutrient data were in 1960 and early 1965. Minor element data were virtually nonexistent, with only four samples being analyzed in the late 1950s. Suspended sediment data are available on a near monthly basis from December 1958 through June 1961 and in early 1965. Pesticide samples had been collected on only four dates.

The Colusa Basin Drain near Knights Landing (AO-2947.10) is located about 3 miles upstream from the outfall to the Sacramento River. Mineral data are available from 1957 through the present. Good records are available for 1957 through 1960, 1965, 1967 through 1974, and 1980 through 1982. Mostly field data (temperature, DO, pH, EC, and turbidity) are available for 1974 through 1979 and 1983 to the present. The most complete nutrient data were collected between 1969 and 1983. Data from 1957 to 1969 and 1983 to the present are sketchy. Minor element data are very limited, with monthly data available from early 1981 through mid-1982. There are good suspended sediment records for late 1975 through late 1982, while pesticide data are extremely limited.

Two monitoring stations are located on the river. The Sacramento River above the Colusa Basin Drain (AO-2230.02) is located about one-half mile above the CBD outfall, while the Sacramento River below Knights Landing (AO-2195.01) is located about 5 miles below the outfall. Mineral data above the outfall are available from 1960 to the present. From the mid-1970s to the present, most of the information is field data only, except in 1983 and 1984, when more laboratory analyses were completed. Fairly complete nutrient data were collected above the outfall from 1960 through 1983 and then became sketchy. Minor element data above the outfall were collected in the spring and fall from 1960 through 1972 and are very limited thereafter. Suspended sediment data are available between fall 1975 and spring 1983 on a near monthly basis. Pesticide data are extremely limited.

Mineral data for the river below Knights Landing are available for 1960 through the present with a large data gap between mid-1961 and mid-1967. Much of the information is field data only after the early 1970s. Nutrient, minor element, and pesticide data are very limited. A fairly complete monthly record for suspended sediments is available between late 1975 and late 1982.

The Colusa Basin Drain at Highway 20 (AO-2976) has mineral records ranging from 1952 to the present.

Sodium was generally the dominant cation in the CBD water historically and, at times, accounted for over 50 percent of the cations in milliequivalents per liter. The bicarbonate ion was generally the dominant anion. Unfortunately, very little complete mineral data have been collected in recent years to determine if there have been any changes.

According to the water quality requirements reviewed by the U. S. Bureau of Reclamation (September 1973), CBD water is usually Class I for agricultural use. At times, the water is Class II with respect to EC, but this is usually during nonirrigation periods and would have detrimental effects on only sensitive crops.

Total ammonia plus organic nitrogen values for the CBD near Knights Landing has ranged from 0 to 2.2 mg/L, while total phosphorus has ranged from 0.06 to 0.46 mg/L.

While the WDIS minor elements data are limited for the CBD, monthly samples collected between February 1981 and May 1982 showed some elevated levels for total copper, total lead, and total selenium. Total selenium values ranged from 0.00 to 0.39 mg/L and exceeded chronic toxicity standards for protection

of aquatic life (EPA, 1986) in June, September, and November 1981 and May 1982. In addition, the acute toxicity level for selenium was exceeded in July 1981. Chronic toxicity levels for lead were also exceeded in September 1981 and March and April 1982. Values ranged from 0.00 to 0.04 mg/L. Chronic toxicity standards for copper were exceeded on every sampling date except two during 1981 and 1982, and acute toxicity levels were exceeded in August 1981 and May 1982. Total copper values ranged from 0.02 to 0.04 mg/L. It should be noted that the WDIS data for minor elements are totals and not dissolved values. The elevated values may reflect copper, lead, and selenium bound to suspended sediments and organic matter carried by the CBD.

The Sacramento River, in contrast to the CBD, is generally calcium-magnesium bicarbonate in nature. Mineral constituents, EC, pH, and turbidity are lower in the river than in the CBD (Table 2). Nutrient levels (ammonia plus organic nitrogen and total phosphorus) in the river are also generally lower than in the CBD. Dissolved oxygen, on the other hand, is generally lower in the CBD than in the river (Table 2).

27. Hayes, S. P.; A. W. Knight; D. E. Bayer; and G. R. Sanford. The effects of irrigation return water on aquatic plants (periphyton) in the Sacramento River at Knights Landing, California. Water Resources Center. Contribution No. 167. University of California, Davis. 75 pp. 1978.

The characteristics of irrigation return water from the Glenn-Colusa Irrigation District and its impact on Sacramento River water were studied for three summer irrigation seasons (1973-75). Stations were set up above, in, and below the CBD at Knights Landing. Water samples were collected and analyzed for levels of suspended matter, turbidity, conductivity, major cation and anion concentrations, temperature, and pH (abiotic parameters). Biotic parameters (densities of dominant diatoms, total diatom density, chlorophyll a, b, and c, and organic matter) were obtained from periphyton communities harvested on glass substrates.

Colusa Basin Drain water was found to differ significantly from the Sacramento River and to have an impact on the river below the CBD outfall. Two major patterns were apparent. Abiotic parameters (except pH in 1975) were higher in the CBD than in the Sacramento River and caused higher values in the river below the outfall. Values gradually decreased downstream to a level slightly above the levels found above the outfall. Biotic parameters showed the opposite trend, with significantly lower measurements in the CBD than in the river above the outfall, with little effect on downstream stations in the Sacramento River.

The impact of CBD water on the river occurred for a considerable distance below its outfall. Only at a station 1,990 meters below the outfall did the abiotic parameters return to near above outfall levels. Since some biotic factors peaked in the below outfall stations, CBD water may have enriched the river.

Aquatic vegetation in the study area was primarily limited to periphyton in the upper half meter of the water column.

Lower biotic factors in the CBD may have been due to scouring, smothering, or shading of periphyton by the high suspended sediment load. In addition, low

Table 2. Summary of basic water quality information and nutrients for the Colusa Basin Drain and Sacramento River (mean = x, standard deviation = s) in the 1980s.

Parameter		CBD near Knights Landing	Sacramento River above CBD	Sacramento River below Knights Landing
Dissolved Oxygen (mg/L)	x	8.3	9.9	9.8
	s	1.6	1.0	1.1
	Range	5.0-11.9	7.6-12.5	7.4-12.1
pH	x	7.9	7.6	7.7
	s	0.3	0.2	0.2
	Range	7.3-8.6	7.2-8.2	7.2-8.4
Electrical Conductivity ( mhos/cm)	x	61.9	15.9	18.9
	s	22.7	23	41
	Range	240-1,340	105-230	104-278
Turbidity (NTU)	x	53	21	25
	s	61	35	36
	Range	7-567	1-212	4-198
Total NH <sub>3</sub> + Org. N (mg/L)	x	0.9	0.3	
	s	0.2	0.2 <sup>1/</sup>	2/
	Range	0.5-1.6	0.2-1.1	
Total P (mg/L)	x	0.20	0.08	
	s	0.05	0.05 <sup>1/</sup>	2/
	Range	0.11-0.39	0.04-0.32	

1/ Data are very sketchy after 1983.

2/ Not enough data available.

levels of herbicides may reduce productivity in the CBD. A trace of molinate was observed on one occasion, while extremely low levels of MCPA were present during its application period.

28. Hunt, E. G. Fish population studies in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FWIR-1. 1964.

The objective was to determine the effects on fish populations of pesticide residue drainage from agricultural lands. Catfish were collected from three major agricultural drains (the CBD, the Sutter Bypass, and the San Joaquin River) and analyzed for pesticide residue (DDT, DDD, DDE, Endrin, and Dieldrin). The highest concentrations were found in the CBD. Therefore, this drain was selected for further detailed study of the chronic effect of pesticides on fish and other aquatic animals.

29. Hunt, E. G. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FWIR-2. 1965.

Fish (white and channel catfish and black bullheads), other aquatic animals (mallard duck, pied-billed grebe, and Pacific pond turtle), water samples, bottom mud samples, and suspended solids were collected and analyzed to determine the degree of pesticide contamination in the Colusa Drain. Samples were collected from two stations in December 1964 and March, April, and May 1965. Low residues were found in the water, suspended solids, and bottom mud. Analytical results were not available for the fish except one black bullhead with low residues. The Pacific pond turtle had high residues of DDE in its fat.

30. Hunt, E. G. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FWIR-3. 1966.

Twelve fish samples, six clam samples, and four water samples were collected and analyzed for pesticide residue. Eleven fish flesh samples (white and channel catfish) were collected in May 1965. Levels of DDT found in catfish in 1965 ranged from 5 to 50 ppm (based on extracted fat) and 20 to 1,070 ppm in 1964. This reduction may have been a reflection in changing agricultural practices since DDT use was decreased drastically in 1964.

Three species of clams were collected (Anodonta nuttalliana, Gonidea angulata, and Corbicula fluminea). Corbicula was found in abundance and showed the highest residue values. High values were found in August 1965, reflecting high summer pesticide use. Fish make up the main food item of catfish in the drain. This may be a reflection of a shortage of benthic organisms (except clams) that was found in 1965. It was recommended that further studies are needed on the effects of pesticide residues on benthic productivity.

Preliminary tests were made of the effects of the organo-phosphate insecticide Dursban on green sunfish in rice fields when applied at mosquito control levels (0.025 and 0.05 pounds/acre). The first test (conducted in May) was inconclusive, since the water temperature reached 97 F, which may have caused the fish mortality. A second test (conducted in June) resulted in the death of all the fish when Dursban was applied at 0.05 pounds/acre, and the death of 2 of 30 fish when applied at 0.025 pounds/acre. It was concluded that Dursban should not be applied at rates above 0.025 pounds/acre.

31. Hunt, E. G. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FWIR-4. 1967.

Four white catfish and one channel catfish were collected from the CBD during July and December 1966. Flesh samples were analyzed for chlorinated hydrocarbon residues (DDT, DDD, DDE, Aldrin, and Kelthane) and percent fat.

Pesticide levels in the fish were much higher than the previous year and approached the levels reported in the first study (1964). Aldrin residues were

found in all of the fish but were considered questionable, since Aldrin is changed to Dieldrin in biological systems. The project was discontinued because of a lack of manpower.

32. Langenour and Meikle Civil Engineers. Colusa Basin Drain Action Group. 130 pp. June 1981.

Chapter 2 contains a fairly detailed account of historic reclamation and development of the Colusa Trough area. It also lists the early as well as most recent reports and investigations of the Colusa Basin.

Chapters 3 and 4 relate to the physical capacities of the CBD Channel and Willow Creek at various places and point out some of the possible restrictions.

Chapter 5 discusses the effects of land leveling, stream channel straightening, and various farming practices on the runoff characteristics within the Colusa Basin. It also discusses how the additional applied irrigation water from the Tehama-Colusa Canal may impact the drainage problems. Sediment and subsidence, aggravated by development, are also discussed.

Chapter 6 discusses present management practices and recommends future management practices, mainly canal maintenance.

33. State Water Resources Control Board. Toxic substances monitoring program, 1984. 116 pp. 1984.

The Toxic Substance Monitoring Program (TSMP) began in 1976 by the State Board to develop data representing baseline and trends of toxic substances in fresh waters of the State. The DFG collects and analyzes muscle and liver tissues of aquatic organisms from selected waters for the presence of trace metals and synthetic organic compounds.

This report includes a section that summarizes data collected between 1978 and 1984. The report includes some data on the CBD. Fish species analyzed in the CBD included brown bullhead, channel catfish, carp, and sucker. Sampling dates in the Drain included October 23, 1980, July 23, 1981, and August 14, 1984.

Trace elements detected in the flesh of CBD fish include cadmium, copper, lead, and zinc, while mercury has been detected in liver samples. In one 1980 sample, mercury levels (0.58 ppm wet weight) were above the NAS guideline of 0.5 ppm on a wet weight basis for the protection of aquatic organisms.

Organic chemicals detected in the flesh of fish from the CBD include chlordane, dachthal, DDT and its breakdown products, dieldrin, endosulfan, alpha HCH, nonachlor, PCB, toxaphene, and chemical group A (combined concentration of aldrin, dieldrin, endrin, heptachlor, heptachlor epoxide, chlordane, lindane, HCB, endosulfan, toxaphene, and others not found in TSMP). Of these chemicals, dachthal, dieldrin, DDT, chlordane, alpha HCH, endosulfan, PCB, toxaphene, and chemical group A were found at elevated concentrations when compared to other State waters. Toxaphene and chemical group A, however, were the only chemicals to exceed NAS standards (100 ppb wet weight) for the protection of aquatic organisms. Toxaphene levels in 1980 reached 100 ppb and 200 ppb for two fish,

while in 1984, one fish reached 450 ppb on a wet weight basis. Chemical group A concentrations were 249 ppb and 505 ppb for fish collected in 1980 and 1984, respectively.

34. State Water Resources Control Board. Rice herbicides: molinate and thiobencarb. Special Projects Report No. 84-4 sp. 176 pp. April 1984.

This report addressed environmental monitoring in the Sacramento Valley for molinate and thiobencarb, risk assessment for both chemicals to fish and humans, and recommended pesticide use and water management practice alternatives to minimize discharge and mitigate adverse impacts to beneficial uses of water.

During a five-year period from 1977 to 1982, the application of Ordram and Bolero more than tripled in the Sacramento Valley. The quantity and concentration of these herbicides discharged into State waters depend on the rate of application, field water retention time, volatility, adsorption to sediments, temperature, and type of irrigation practice.

During the rice-growing season, up to one-third of the Sacramento River flow between Knights Landing and the City of Sacramento consists of rice field drain water.

During 1983, high river flows caused the CBD return flows to be diverted down the Yolo Bypass into Cache Slough in the delta. Water samples from Prospect Slough contained 98 ppb molinate and 4.5 ppb thiobencarb. Fish from Prospect Slough contained up to 1,000 ppb molinate and 700 ppb thiobencarb. Molinate was also detected (10 µg/L) in the northern extreme of Cache Slough.

Calculation of "worst-case" Sacramento River concentrations during low-flow years indicated that peak molinate concentrations could exceed DFG guidelines for the aquatic biota, while thiobencarb concentrations would not.

During the rice herbicide season, the highest concentrations of both molinate and thiobencarb have been detected in the edible portions of catfish and carp from agricultural drains (over 2,000 ppb).

35. State Water Resources Control Board. 1985 data associated with the draft Sacramento River toxic chemical risk assessment project.

Data collected on November 9, 1985 are presented for trace elements in sediments of the CBD, other agricultural drains, and several river stations. Replicate samples were sent to two separate laboratories. Metal concentrations in CBD sediments were higher for chromium nickel, and lead than in river sediments at Colusa. Copper and zinc values were higher in the CBD sediments than the river, according to one set of laboratory results, but lower for the other laboratory results. Mercury was below detection limits, while cadmium was found at low concentrations by one laboratory.

Water quality data for the river and drains are presented in tabular form for the period from May to December 1985. Analyses included pH, EC, temperature, hardness, suspended solids, aluminum, arsenic (total and dissolved), boron, calcium, cadmium (total and dissolved), chromium (total and dissolved), copper

(total and dissolved), iron, magnesium, manganese, sodium, nickel (total and dissolved), and zinc (total and dissolved). Mineral and trace metal constituents were nearly always higher in the CBD than in the river near Colusa. Arsenic was detected in the CBD on one date, while cadmium was never above detection limits. Chromium, copper, and zinc were detected in the CBD on most of the collection dates, while nickel was found on only three dates. Mercury, selenium, tin, and antimony were always below detection limits.

36. State Water Resources Control Board and Central Valley Regional Water Quality Control Board. 1983-86 data.

Colusa Basin Drain flows in 1983 were diverted down the Knights Landing Ridge Cut to the Tule Canal, Liberty Cut, and Prospect Slough due to unusually high river flows. Molinate levels in the Toe Drain ranged between 50 and 98  $\mu\text{g/L}$ , similar to those in the CBD. As a result of the herbicide discharge from Prospect and Cache Sloughs, molinate levels in the river near Rio Vista were approximately double those in the upper river (Table 3).

Lower concentrations of molinate were found north of Prospect Slough in Shag, Lindsey, and upper Cache Sloughs. No other source of drainage water was identified; therefore, drainage water from Prospect Slough was making its way upstream, probably due to tidal action, and reverse flows due to pumping in upper Cache Slough for the City of Vallejo and Travis Air Force Base. The highest molinate concentration in upper Cache Slough was 11.5  $\mu\text{g/L}$ . Sampling at the Vallejo intake canal on June 29 detected molinate at 1.8 to 6.9  $\mu\text{g/L}$  (Table 3).

Molinate and thiobencarb were detected in Prospect Slough fish. Molinate levels ranged from 100 to 1,000 ng/g, while thiobencarb levels ranged between 100 and 700 ng/g.

During 1984 through 1986, molinate and thiobencarb levels were much reduced in the northern delta area (Tables 3 and 4). During these years, the CBD was again discharging to the Sacramento River at Knights Landing.

37. State Water Resources Control Board and Central Valley Water Quality Control Board. -Sacramento River toxic chemical risk assessment project. Draft interim report. 194 pp. March 1986.

This study was initiated in 1984 to investigate sources of toxic chemicals (trace elements and synthetic organic compounds), examine potential effects on anadromous fish and drinking water supplies, and recommend corrective management practices for the Sacramento River.

The river from Shasta Dam to Collinsville was divided into six reaches. Agricultural drainage, acid mine drainage, urban drainage, point source emissions, and tributary inflows were identified by reach.

The top 100 pesticides used in the Sacramento Valley were grouped into three categories: those applied directly to water, those applied during the storm season, and those applied during the dry season. Dry season chemicals were further ranked according to their persistence, timing of application, and

Table 3. Levels of Ordram (molinate) in the delta.

Location	Range of Molinate Values (ug/L), Number of Samples (parentheses)			
	1983	1984	1985	1986
<u>Sacramento River</u>				
Freeport	-	8.9-14 (4)	8.0-13.0 (2)	1.3-12.0 (6)
Walnut Grove	-	9.6-14 (4)	8.0-13.0 (2)	9.0 (1)
Rio Vista	10.0 (1)	9.2-10.0 (4)	9.0-10.0 (2)	<0.5-8.0 (8)
Collinsville	-	2.2-8.0 (4)	-	-
<u>Northern Delta</u>				
Toe Drain at I-80	44.0 (1)	-	-	<0.5 (1)
Toe Drain, Prospect Slough	59-98 (2)	1.1-2.4 (4)	1.0-3.0 (2)	2.0 (1)
Shag Slough	24.0 (1) -	-	-	-
Prospect Slough	61-98 (2)	3.3-4.8 (4)	-	-
Liberty Cut	59.0 (1)	-	-	-
Cache Slough				
at Hastings Cut	1.5 (1)	<1.0 (4)	<1.0 (1)	-
at Lindsey Slough	19-38 (2)	5.7-7.0 (3)	7.0-8.0 (2)	6.0 (1)
lower	14.0 (1)	-	-	-
at Vallejo Pump Plant	1.8-10.0 (3)	-	<1.0 (3)	-
Lindsey Slough				
at Hastings Cut	38.0 (1)	-	<1.0 (1)	-
at Barker Slough	-	-	<1.0 (2)	-

1983: Analysis by California Analytical Laboratories (Stauffer, Chevron, DFG values not reported here).

1984, 1985: Analysis by Stauffer and Chevron.

1986: Analysis by California Analytical Laboratories, Stauffer, Chevron.

octanol water partitioning coefficient (log KOW). Those chemicals that were detected in fish are either directly applied to rice fields or bioaccumulate in aquatic organisms.

Molinate, thiobencarb, methyl parathion, ethyl parathion, and MCPA have been detected in major agricultural drains (including the CBD), but only molinate and thiobencarb were detected in the river above 1.0 µg/L. Levels of these two chemicals in the river were proportional to the drain:river dilution ratio. Molinate and thiobencarb have also been detected in the flesh of fish from the CBD.

Chlorinated pesticides (chlordan, dacthal, dieldran, DDT, dicofol, endosulfan, and toxaphene) have been found in the flesh of river fish. Chlordane in fish fillets from the Sacramento River exceeded NAS guidelines for the protection of aquatic organisms.

Table 4. Levels of Bolero (thiobencarb) in the delta.

Location	Range of Bolero Values (ug/L), Number of Samples (parentheses)			
	1983	1984	1985	1986
<u>Sacramento River</u>				
Freeport	-	<1.0-1.4 (4)	0.9-1.3 (2)	<0.5-0.7 (6)
Walnut Grove	-	<1.0-1.1 (4)	0.5-2.0 (2)	0.6-(1)
Rio Vista	<0.5 (1)	<1.0-1.0 (4)	1.0-2.3 (2)	<0.5-<1.0 (7)
Collinsville	-	<1.0-1.6 (4)	-	-
<u>Northern Delta</u>				
Toe Drain at I-80	2.8 (1)	-	-	<0.5 (1)
Toe Drain, Prospect Slough	2.5-3.3 (2)	<1.0 (4)	<1.0 (2)	<0.5 (1)
Shag Slough	<0.5 (1)	-	-	-
Prospect Slough	2.1-4.5 (2)	<1.0 (4)	-	-
Liberty Cut	2.5 (1)	-	-	-
Cache Slough				
at Hastings Cut	<0.5 (1)	<1.0 (4)	<1.0 (1)	-
at Lindsey Slough	1.5-2.2 (2)	<1.0 (3)	<0.5-1.5 (2)	<0.5 (1)
lower	<0.5 (1)	-	-	-
at Vallejo Pump Plant	<0.5 (3)	-	<0.5-<1.0 (3)	<0.5 (1)
Lindsey Slough				
at Hastings Cut	1.3 (1)	-	<1.0 (1)	<0.5 (1)
at Barker Slough	-	-	<0.5 (2)	-

1983: Analysis by California Analytical Laboratories (Stauffer, Chevron, DFG values not reported here).

1984, 1985: Analysis by Stauffer and Chevron.

1986: Analysis by California Analytical Laboratories, Stauffer, Chevron.

Trihalomethanes have been found in the City of Sacramento's tap water. The possible source has been tied to agricultural drainage, where the DWR found high total trihalomethane formation potentials.

Data collected between May and November 1985 on dissolved and total copper indicated that the CBD and Sacramento Slough are major contributors of copper to the river.

In addition to nonpoint discharges of agricultural return water to the CBD, point sources were presented. These included waste water treatment plant effluent (City of Colusa and City of Willows), sewage treatment plant effluent (City of Williams and Maxwell Public Utility District), and food processing wastes and plant cooling water (Glenn Milk Producers Association).

38. U. S. Bureau of Reclamation. Colusa Basin Study, water quality work team report. 35 pp. September 1973.

This report considered water quality criteria for various beneficial uses and evaluated the basin water quality at that time in terms of those criteria.

Water quality requirements for agriculture were listed with respect to EC, TDS, Cl, Na, B, SAR,  $\text{NO}_3$ , trace elements, pH, and temperature. Requirements for fish are listed with respect to temperature, dissolved oxygen, pH, TDS, and turbidity. The Department of Health Services' standards for public health are also addressed.

The U. S. Public Health Service estimated an increase of 3.2 mg/L TDS in the Sacramento River with deliveries from the Tehama-Colusa Canal to the CBD and the potential for fish kills in the river related to pesticides.

In Bulletin 109, the DWR indicated that water quality in the CBD at Knights Landing almost always contained Class I irrigation water (suitable under most conditions).

Data from 1968 through 1971 indicated that all surface waters in the basin were Class I for irrigation. Drainage water from Reclamation District 787 was high in boron content and may exceed the level (1 mg/L) that may be detrimental to sensitive crops. This water, however, was well diluted by CBD water.

Surface waters were generally adequate for fish and wildlife needs. Dissolved oxygen levels in the CBD, however, were sometimes below 80 percent saturation. Colusa Basin Drain turbidities almost always exceeded 50 JTU and may have some detrimental effect on the fishery.

The CBD near Knights Landing often showed high EC and TDS, but was within the recommended limits for municipal supply. Iron, manganese, and turbidity, on the other hand, frequently exceeded recommended limits.

The CBD affected Sacramento River quality to some extent. Average EC and turbidity rose in the river below the CBD during the irrigation season. Annual averages for EC also rose in the river below the outfall, but turbidity dropped. The drop in turbidity may have been due to closing of the Knights Landing outfall gates during high winter flows. River temperatures increased below the drain, but it was not known if the increase was caused by the the CBD outfall or travel time between stations from above to below the CBD.

The following factors were identified that could cause future changes in water quality in the Colusa Basin: increased reuse of basin water, increased irrigation, new supply from the Tehama-Colusa Canal (this is currently a supply), new agricultural practices (current rice practices are different), increased use of poorer quality ground water, increased wildlife populations, future urban and industrial waste loads, increased recreational use, and irrigation with Bay area sewage.

39. U. S. Bureau of Reclamation. Colusa Drain Unit. Water supply and water rights. 40 pp. December 1973.

The objectives of this study were to: provide information on water rights and supply in the the CBD system; determine the adequacy of the supply and needs for supplementation; identify water rights problems; and recommend actions.

The primary uses of water in the the CBD system are irrigated agriculture, wildlife refuges, and private gun clubs.

A history of the CBD, Knights Landing Ridge Cut, and Yolo Bypass is presented.

The water supply at the time of the report consisted of natural runoff during fall, winter, and spring and return flows in the summer and fall. Most of the return flows were from diversions of the Sacramento River.

40. U. S. Bureau of Reclamation. Colusa Basin Study, environmental appraisal. 23 pp. June 1974.

The purpose of this report was to conduct an inventory of environmental characteristics of the area and develop general plans for areas within the Colusa Basin that should be developed as part of any structural National Economic Development plan.

Flooding problems in the basin occur in the winter when tributary drainage becomes too great for the drainage canals, and during the spring when irrigation return flows are high.

At the time, about 730,000 acres of land in the basin were cultivated, while 750,000 acres were not. Private gun clubs occupied 12,000 acres and the Sacramento, Colusa, and Delevan National Wildlife Refuges and other public lands made up 20,457 acres. Peak waterfowl use occurred between late October and early December. There were about 350,000 acres of wetlands and marshes.

41. U. S. Bureau of Reclamation. Colusa Basin Study, flood prevention and drainage. 59 pp. October 1974.

The purpose of this report was to determine possible alternative means for preventing floods in the basin and to determine the effect of increased drainage return flows from new irrigated land.

The Colusa Basin was once swamp overflow land that filled periodically from high Sacramento River flows. The basin is about 75 miles long, running from Orland in Glenn County through Colusa County to Knights Landing in Yolo County.

The Colusa Basin is an important wintering ground for Pacific flyway waterfowl. U. S. Fish and Wildlife Service records from 1953 to 1974 showed that 80 percent of the 470,000 migratory waterfowl in the Sacramento Valley occupy refuges during September. There are three National Wildlife Refuges in the basin covering about 24,000 acres.

The basin is extensively used for fishing. Catfish, largemouth bass, bluegill, and green sunfish are taken from the CBD and in channels and ponds on flooded gun club lands. In addition, the basin is one of the best pheasant production areas of the State, with an estimated 160,000 acres of land devoted to this game bird. Other game birds that are less widely distributed include mourning dove and California quail. Many nongame species also inhabit the wetland habitat.

Any possible alternative and solution to improve drainage and reduce flooding in the CBD should take into account impacts of increased flows on flooding and water quality in the delta.

Possible benefits of extending the CBD to the Yolo Bypass and eventually to the Suisun Marsh include: water quality enhancement of the Sacramento River between Knights Landing and Rio Vista, the extended drain could possibly serve as a M and I outlet for various cities, the extended drain could act as a drainage outlet for agricultural return flows from Yolo and Solano Counties, the extended canal could act as a source of irrigation water, and the drain waters could be used in the Suisun Marsh for waterfowl and wildlife enhancement.

Because of the Tehama-Colusa Canal, it was predicted that an additional 52,500 acre-feet of agricultural drainage could occur in the CBD under ultimate canal operations.

The following alternatives were identified for consideration to decrease flood problems: foothill storage reservoirs, increased capacity of the Knights Landing Ridge Cut, increased flow capacity of the CBD, and construction of a new drain at a higher elevation and parallel to the CBD.

The following alternatives were identified to alleviate drainage problems in the CBD: creation of a four-county (Glenn, Colusa, Yolo, and Solano) regional drainage entity, initiating a drainage plan for the total irrigable area served by the Tehama-Colusa Canal and Glenn-Colusa Canal, extension of the CBD to the Suisun Marsh and year-round drainage under the Glenn-Colusa Canal.

42. U. S. Bureau of Reclamation. Sacramento River drainage and seepage utilization investigation, California. 93 pp. June 1980.

This report addresses three problems: (1) drainage problems associated with flooding within the Colusa Basin; (2) return flow from irrigation of lands in the Tehama-Colusa service area; and (3) seepage along the Sacramento River.

Nine possible solutions to the spring flooding within Colusa Basin include: construction of foothill reservoirs, improved discharge characteristics; diversion of the northern tributaries to Stony Creek or to the Sacramento River; increased flow capacity of the CBD; pumping of the Colusa Drain to the Sacramento River; construction of a new drainage canal at a higher elevation; diversion of streams to the Tehama-Colusa Canal and to Cache Creek; extension of the CBD to Suisun Marsh; and development of flood-retention reservoirs on the National Wildlife Refuges.

The problem relating to the increase in irrigation return flow due to the Tehama-Colusa Canal and possible solutions are discussed. About half of the report is devoted to seepage along the Sacramento River.

43. University of California, Davis. Return flow water quality appraisal, Glenn-Colusa Irrigation District, calendar year 1973. I: Water balance, salinity, and suspended matter. Water Science and Engineering Paper No. 4007. 23 pp. August 5, 1974.

Inflow-outflow analysis was made on water, electrical conductivity, total dissolved solids, turbidity, and suspended solids during the 1973 irrigation season and outflow during the nonirrigation season for eleven drain laterals to the CBD.

The ratio of drain outflow to diverted inflow was 0.27. Seasonal output:input ratios for EC and TDS were 3.14 and 2.42, respectively. The turbidity seasonal ratio was 3.44, while the suspended solids ratio was 3.00.

Outflow was low in April when rice fields were flooded, increased in May through August, and was highest in September and October when fields were drained for harvest. Output:input ratios for EC and TDS were high in April due to leaching of salts from the past-irrigation season. Turbidity output:input ratios were lowest in April and June and highest in May, August, and September. High May turbidities were due to lowering water levels in rice fields because of high north winds. The output:input ratio for TDS in tons increased progressively over the irrigation season. The ratio of tons of salts in outflow to inflow was 0.65, indicating that 35 percent of the salts brought in by irrigation water were stored in the soil-water system of the district.

Monthly water flow during the nonirrigation season is a function of precipitation pattern and intensity. Flood runoff waters were higher in salt concentrations due to chemical weathering of rocks, minerals, and soils and leaching of accumulated salts from previous irrigation. Turbidity and suspended solids were also generally higher in the nonirrigation season.

Outflows during the 1973 irrigation season were greater than during the non-irrigation season, while flow-weighted average water quality parameters were higher in the nonirrigation season.

44. University of California, Davis. Sediment production and transport in Colusa Basin drainage area, 1977-78. Water Science and Engineering Paper No. 4016. 211 pp. November 1978.

This report presents the first year of investigation on production and transport of suspended matter in the CBD.

Turbidity in the CBD near Knights Landing during the nonirrigation season ranged from 20 JTU in absence of storms to 1,250 JTU during storm events. Turbidity values during the irrigation season ranged from 30 to 220 JTU. Colusa Basin Drain water generally raised turbidity in the river below its outfall by 10 to 20 JTU.

During the nonirrigation monitoring period (November 1977 to April 1978), 860,100 acre-feet of storm water discharged 451,920 tons of suspended sediments from the CBD. During the irrigation season, an additional 376,300 acre-feet of water discharged 53,970 tons of suspended sediments.

At the height of a mid-January storm event, EC ranged from 143 to 437  $\mu\text{mhos/cm}$ , pH ranged from 7.9 to 8.5, and SAR varied from 0.4 to 2.0. At the start of the irrigation season, EC of the supply water was 195  $\mu\text{mhos/cm}$ , while drain waters ranged from 460 to 1,180. The pH of the supply water was 7.8, while drain waters were 8.2-8.5. The SAR of the supply was 0.4 and of the drainage was

0.4 to 2.0, with lateral drains with sodium-affected soils having the highest values. Mid-summer water quality in the drain is generally better because much of the soluble salts have already leached and turbidity in the rice fields has stabilized. In August 1978, the CBD water raised EC in the river by 31  $\mu\text{mhos/cm}$  and SAR by 0.20. The pH, suspended solids, turbidity, nitrogen, and phosphorus content of the river was not changed significantly by the CBD in August.

Colusa Basin Drain water temperatures in August ranged from 71 to 92 F, while dissolved oxygen saturation values were 72 to 97 percent. Algal biomass in the lower CBD (2.4 to 6.6 mg/L) were lower than the supply waters (4.7 to 9.6 mg/L) and were apparently inhibited by turbidity in the drain.

Records from 1969 to 1971 on turbidity showed an irrigation season average for the CBD of 129 JTU, which increased river turbidity an average of 10 JTU's from 28 above the outfall to 38 below the outfall. During the summers of 1973, 1974, and 1975, the average suspended solids concentration in the lower CBD was 106 mg/L, which caused an increased in suspended solids in the river an average of 13 mg/L.

45. University of California, Davis. Nonpoint sediment production in the Colusa Basin drainage area. Second-year annual progress report on EPA Grant No. R805462, October 1978-September 1979. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4018. 379 pp. 1980a.

The CBD conveys flood runoff and irrigation return flows from about 1 million acres of watershed and agricultural land on the west side of the Sacramento River. It is one of the two largest sources of agricultural return flows discharged into the river. Data indicates that the CBD contains a significant amount of suspended solids that raises the turbidity of the Sacramento River, especially during storm runoff.

This project attempts to identify nonpoint sources of suspended matter in the CBD area, to understand factors contributing to or affecting suspended solids loading, and to develop recommendations for best management practices.

The basin was divided into 24 subbasins in which sediment production was estimated. Comparisons were made between estimated and measured sediment loadings at selected sites and in subbasins.

Weekly monitoring of flows and suspended matter was conducted at eleven stations. Monitoring on a monthly or more frequent time interval was conducted on an additional fifteen stations.

The data showed that highest concentrations of suspended solids coincide with peak storm flows. Maximum and average suspended solids concentrations were greater in the nonirrigation season.

Three general areas of concern were identified: bare level basin soils, moderate to steep cultivated soils, and steep noncultivated foothill land. Recommended management practices include: careful management of soil cover and grazing animals on steep noncultivated land; prudent farming practices utilizing grassed waterways and contour strips on cultivated steeper lands; and farm water conservation and water recycling on level basin soils.

When current velocity is high in the CBD, bed materials tend to be coarser. When velocity drops, small silt and clay particles accumulate.

The organic carbon content of the suspended matter was comparatively small (1.5 to 4 percent), indicating that sediments are essentially mineral in character.

River water contained one-fifth the suspended solids concentration and had twice the organic content.

The sediment makeup, determined by x-ray diffraction, is discussed.

From a water quality standpoint, there is significant erosion and sediment production in the CBD. Approximately 269,000 tons of soil or 177 tons/ square mile could be eroding yearly.

46. University of California, Davis. Nonpoint sediment production in the Colusa Basin drainage area. Annual report to EPA on EPA Grant No. R805462, 1979-1980. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4019. 157 pp. 1980b.

This project was a continuation of the 1977-79 project. Monthly or more frequent monitoring of fifteen stations continued. Three pesticides were chosen for monitoring during this study.

Once again, highest concentrations of suspended solids coincided with peak storm flows and were greatest during the nonirrigation season.

Organic content of sediments was low. Sediments were largely mineral and derived from soils of the Colusa Basin.

Sodium, sulfate, and bicarbonate were the dominant soluble ions in the CBD. While sodium was the dominant soluble cation, it was lowest among the exchangeable cations adsorbed to suspended matter. Calcium and magnesium dominated among exchangeable cations.

In February, April, and September, pesticide concentrations (MCPA, molinate, and parathion) were below detection limits in the CBD. In May 1980, there was an increase in molinate concentration.

An analysis of CBD suspended sediment showed an increase with downstream progression in algal biomass and concentrations of total dissolved solids, suspended solids, and organic matter. Algal biomass was exponentially correlated with orthophosphate in the drain ( $r = 0.91$ ).

47. University of California, Davis. Sediment characterization and transport modeling in Colusa Basin Drain. Water Science and Engineering Paper No. 4021. 259 pp. December 1981.

Suspended sediment (mg/L) concentrations in the CBD are much greater in the nonirrigation season (October-March) than in the irrigation season (April-September). Sediment discharges from the CBD appear to have a significant

effect on bed material in the Sacramento River. The samples in the river upstream from the CBD were gravelly, while samples downstream were predominated by medium sand.

Bed materials in the CBD show the pattern of coarse materials in areas of high current velocity and steep slope and fine materials in areas of low velocity and mild slope.

Algal biomass in the CBD was controlled, in order of significance, by orthophosphate, nitrate, ammonia, and temperature. Combined, these four factors could account for 99 percent of the variation in suspended algal biomass.

Total dissolved solids (TDS) over a 3-year period (1977-79) ranged from 200 to 800 mg/L and averaged 400 at the CBD near Knights Landing. Total dissolved solids values were generally lower during storm runoff periods and periods of high agricultural return flows (August). The pH values ranged from 7.4 to 8.4 in the CBD with concentrations of cations ranging from 1.2 to 9 mg/L and sodium absorption ratio (SAR) ranging between 0.4 and 4.9.

Three general categories make up suspended sediments in the CBD. Mineral sediments (silt and clay) accounted for 60 percent, while phytoplankton (living and dead) made up 10 percent and suspended organic matter made up 30 percent.

48. University of California, Davis. Nonpoint sediment production in the Colusa Basin drainage area. Annual report to EPA on EPA Grant No. R807169, 1980-81. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4022. 126 pp. 1981.

This report completes the final year of study and involved factors and causes contributing to the turbidity problem in the CBD. The CBD was monitored for flow, turbidity, total dissolved solids, conductivity, and suspended solids.

The discharge of water and sediment from the CBD in 1981 was less than previous years because the amount of precipitation was less.

Linear relationships were established between suspended solids and current velocity, flow rate, and turbidity.

Of the water delivered to irrigated croplands in 1981, three-fourths was used in rice production.

Once again, concentrations of suspended solids were higher in the nonirrigation season.

The plume originating at the CBD outfall at Knights Landing was studied to determine the effects of the CBD on the Sacramento River. Nine stations were monitored for turbidity, conductivity, color, and chlorophyll-a.

Turbidity decreased as CBD water mixed with the river. Suspended particle concentrations decreased exponentially with plume width. Water from the CBD increased the conductivity of the river substantially. Color also increased

with the maximum change occurring in late September, corresponding to an increase in discharge from rice fields with a high concentration of suspended organic particles.

The pesticide molinate showed a steady and rapid increase in the CBD from April to June 1981 and rapidly decreased in June. Methyl paration was also detected.

A dynamic mathematical and computer model was developed for simulation of suspended matter transport in the CBD. A user's manual was developed and completed.